DESIGN OF A SEWAGE IRRADIATOR USING CESIUM - 137 WASTE FORMS

FINAL REPORT

PROJECT E-26-633 (SRP PURCHASE ORDER AX0598189)

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SUMMARY

To provide for economic utilization of prospective vitrified cesium-137 waste elements, a study was conducted for a conceptual irradiator system based on these elements for the commercial sterilization of sewage sludge. Such sterilized sludge has uses for land spreading as fertilizer.

A literature study was performed and an evaluation was made of the relative merits of irradiating wet or dried sludge. It was concluded that dried sludge, though more expensive, could be sterilized more efficiently.

Bacteriological tests on sewage sludge demonstrated that adequate destruction of E. coli in sludge could be obtained with radiation doses as low as 150 kR. However, to meet EPA guidelines and to reduce any virus infection, a dose of about 1 megarad is generally regarded as mandatory.

Two cesium waste concentrations had been proposed. Of the two it was evident that the one incorporating lower concentrations of Cs-137 and a surface dose of 20 kR/hr was insufficiently active for the present purpose. Work, therefore, concentrated on the more active source cylinders, which are 18 cm in diameter with a specific activity of 16-17 Ci/cc.

The conceptual design envisages the dry sludge passing horizontally by a conveyor system, past two rows of source elements in a three-pass array. A computer program has been developed to produce isodose contours and to calculate integrated doses for various source-target configurations. Because of the low specific activity and the bulk of the source cylinder, a relatively high source strength is required for a reasonable plant capacity.

PROJECT PERSONNEL (all parttime)

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INTRODUCTION

The treatment of waste water normally produces two outputs--purified water that may be released to the uncontrolled environment and solid material that has been removed from the water. The latter is gathered in the form of sludge scraped from the bottom of processing basins and subjected to bacterial degradation either aerobically or anaerobically. The result is a mixture that typically contains 3 or 4% solids and is almost completely stabilized.

There are two possible routes for ultimate disposal of these solids. They may be dewatered and then incinerated or buried, procedures that are direct costs, supply no environmental benefit and provide no income to offset any of the treatment costs. The alternative is to direct these solids into a use that provides some financial or environmental advantage.

The obvious use of sludge is for fertilizer, as the dried solids have a nitrogen and phosphorus content of a few percent and the organic matter present will improve the tilth of many soils. However, the sludge may contain a variety of pathogenic entities and toxic chemical components, such as metals which may build up in the soil following repeated applications. The biological hazard is of more concern, as pathogens may be present in any sludge, whatever the origin of the wastewater from which it is recovered. The use of sludge for agricultural purposes is, therefore, restricted unless the potential biological hazard is removed. Stabilization can be accomplished by heat, by gamma radiation, or by a combination of both. Due to high energy costs, heat sterilization would normally be used only in situations where a well-dried end product is required. Gamma radiation, on the other hand, can be effectively used on materials wet or dry.

The design of gamma irradiators is a fairly well-developed technology in which the designer has control of the specific activity of the radioactive sources to be used. In the present instance, however, the source material is to be cesium-137 in the form of a waste material resulting from operations at the Savannah River Plant. The conceptual design study presented here is, therefore, based on the activity and dimension of the cylinders of encapsulated, solidified waste that are now available or can be produced with little change in existing procedures at the SRP.

The technical and economic feasibility of the use of SRP waste sources depends on the dose rate that can be achieved in the sludge. If the dose rate is too low, the time required to deliver the necessary total dose is excessive. Neither a long irradiation period nor compensation with vast numbers of sources is acceptable. For purposes of a generalized first approach, it was assumed that two or three hours in process would be acceptable. Based on the literature, the general consensus appears to support a total dose of one megarad as sufficient. The practicality of an irradiator, therefore, depends on the ability to deliver one megarad to the sludge in an acceptable time period with a reasonable number of sources.

PREVIOUS WORK

Radiation chemistry was a popular research area in the 1950's and 1960's and it was early recognized that ionizing radiation provided a convenient, non-invasive means of sterilizing a variety of materials, such as medical supplies or mattresses, and various irradiators were designed for this purpose (Eichholz, 1972). The treatment of sewage and waste water by irradiation was identified as a potentially useful application for radioisotope sources and several economic studies and conceptual designs were published (Dunn, 1953; Ballentine 1969, 1971; Compton et al., 1970, 1971; Mytelka, 1969, 1971; Whittemore et al., 1970). Most of these employed cobalt-60 as the source material and had three objectives: sterilization of waste water to drinking water standards, improved settling conditioning for suspended solids, and treatment of sewage sludge. At the scale envisaged and the price of cobalt-60, most of the proposals did not seem to be economically competitive, nor could they be promoted as municipal works, given the public attitude to anything involving radiation sources.

A major commercial sales effort was sparked by Woodbridge (1970), who, however, made excessive claims for a waste water treatment system involving both radiation and chlorination. There the matter rested until the U.S. Environmental Protection Agency and the Department of Energy initiated two programs intended primarily to treat sewage sludge for land spreading and sterilization of waste water. One such project involved the use of an accelerator to use electron bombardment of thin water layers. This project, done with High-Voltage Engineering Corp., led to a demonstration plant at Deer Island, Mass. The other project has been a continuous effort by Sandia National Laboratory to use Hanford cesium-137 sources to design a sludge irradiator (Morris et al. 1978-1980; Sivinski et al. 1975-1979, and current progress reports). This work reportedly is currently leading to a planned demonstration plant at Albuquerque N.M. At the same time interest has been expressed by other commercial companies in developing municipal waste irradiation systems (Auxier, private communication).

In parallel with the above developments there has been interest in synergistic applications of radiation sources in waste treatment, primarily as a primary stage to promote degradation of toxic or noxic chemicals prior to biological digestion. Such processes have been described by Case et al. (1971) and for dye wastes by Craft and Eichholz (1971,1973). Other pilot operations for sludge treatment have been set up in Switzerland (Herrnhut et al. 1974, 1976; La Roche, 1976), Italy (Piccinini et al., 1982) and Germany (Hegemann and Guenthert, 1976) with fairly encouraging results.

The presence of large quantities of solidified cesium-137 waste forms has made that material an attractive alternative to cobalt-60 and has changed the economic factors to some extent. By avoiding or deferring high disposal costs for waste materials in engineered disposal facilities, constructive uses may result in an overall savings in the waste scenario. These considerations have provided the impetus for current DOE interest in this field (Fradkin, 1982; Krenz and McMullen, 1982). The present project is part of this waste utilization effort.

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TARGET DOSE SELECTION

General Review

The purpose of this section is to justify a reasonable gamma ray dose to be used in the design criteria of a sewage sludge irradiator for the purpose of producing a fertilizer of suitable quality and safety applied in the growing of crops for human consumption. The primary concerns in determining the dose were: bacteria and viral pathogen destruction, compliance with existing regulations, and a reasonable margin of safety in using the product. Since bacteria for the most part have a lower D-value than viruses[6], the lower limit on the dose will have to be set by the most resistant species in sludge in order to ensure a reasonable margin of safety. For this reason, the following will be primarily focused on viruses and the importance in determining an adequate dose for the design of a sludge irradiator.

The virus population of waste water consists of large quantities (10^5/l) of viruses excreted with human feces.[6] There is adequate documentation noting that virus infections are widespread in a normal population, with the highest infection rates in children under the age of 15 years old. It has been shown that about 10 percent of the children will be shedding viruses at any given time.[1,2,3,4] Even though a large number of viruses are excreted, most studies on waterborne pathogens have been directed toward the human enteric viruses due to their ease of detection.[1,2] Waterborne transmission of a virus has only been documented in the case of infectious hepatitis.[1]

For our purposes, the concern was the transmission fo the viruses from the soil, where the sludge (solid or liquid form) was spread, to crops and eventually back to man. Several studies have been done, illustrating the survivability of viruses on soil. In a field study of Poliovirus survival in soil conducted by Tierney et al., (1977), Poliovirus I (LSC 2AB) inactivation rates were compared in vegetable plots flooded with either activated sludge or secondary effluent containing approximately 2.5×10^5 PFU (Plaque Forming Units)/ml of the virus. In the winter months, poliovirus was detected for 96 days in sludge-flooded soil and for 89 days in effluent-flooded soil. The summer months showed recoverable virus from the soil for only about 2 weeks and from nonsterile soil for only 2 to 3 weeks. In still another study, virus was found as long as 134 days in soil with a moisture content of 25 percent and a temperature of 20^oC; however, none was found in drying soil at the same lengths of time. To summarize the studies done, longer virus detectability was favored by sandy soil, sterile conditions, low temperature ($3-10^oC$), at least moderate moisture content and a mildly alkaline pH. (7.5).

Since the survivability of viruses enhances the potential for an oral-fecal route to become established using sludge fertilizer, virus destruction will be incorporated into the design of the irradiator in this project. Some studies done on raw sludge using Poliovirus as an indicator showed that sludge is protective against ionizing radiation, but that small concentrations are nearly as protective as large concentrations. Sludge has also been found to be unsuitable as an environment for virus replication. This would mean that viruses do not regrow in numbers after reduction by a particular treatment and that the virus viability in treated sludge would be a function of the cumulative effects of all stages of the treatment. This fact, however, is not true of other pathogens, such as Salmonella and fecal Streptococcus, which can multiply in composted sewage sludge.[6]

The process by which most waste is treated is depicted in Figure 1. In this process, the treatment by which destruction of bacterial and viral pathogens is obtained is the anaerobic digestion step in the waste treatment process. The anaerobic digestion processes have been found to reduce bacterial pathogen populations in sludge by 90 to 95 percent. It has also been found in experiments using indigenous and seeded viruses in sludge, that anaerobic digestion removes about 90 percent of the

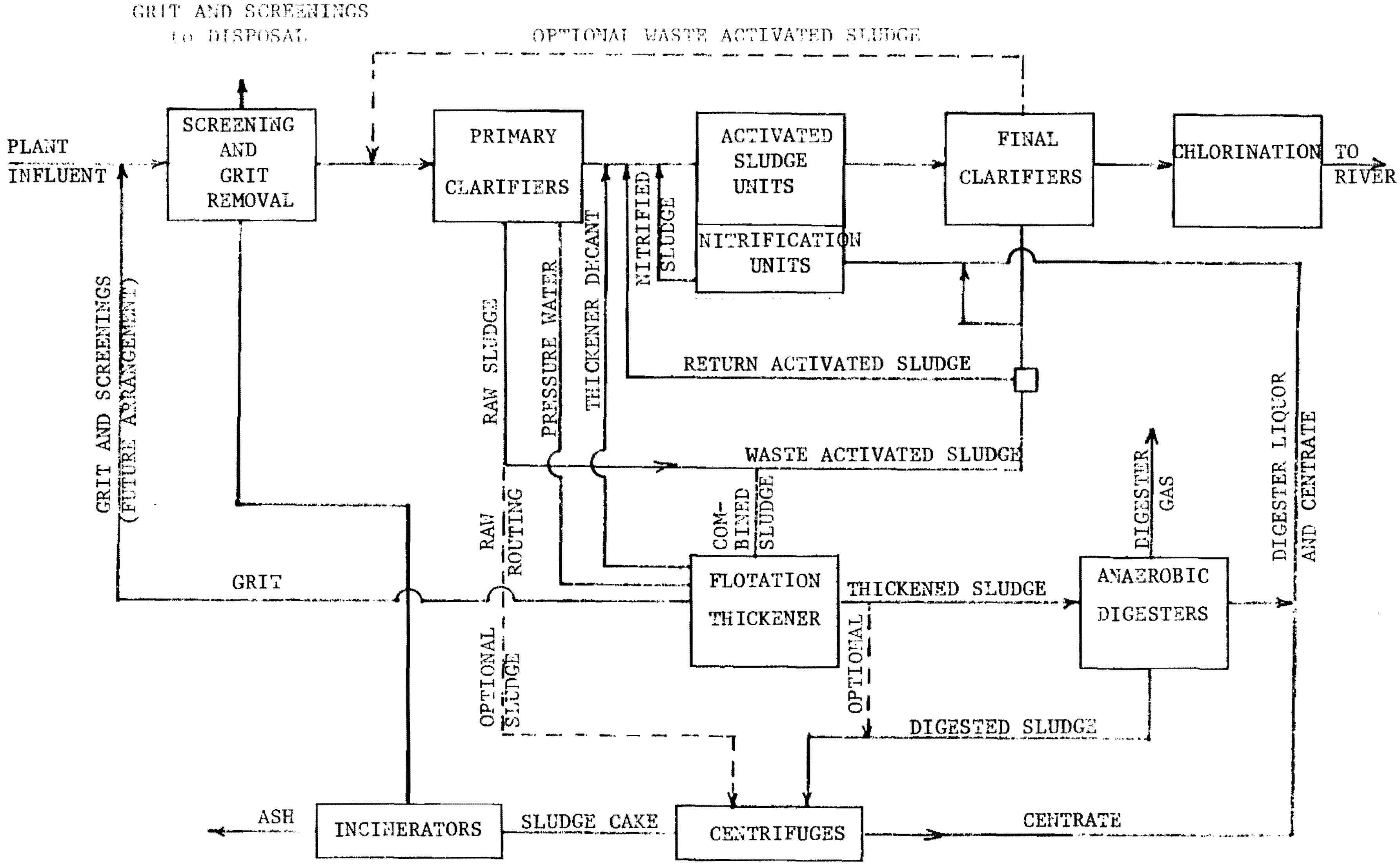

Fig. 1 Process flow diagram for R.M. Clayton WPC Plant

detectable viruses from sludge.[8] In another study, a loss of 25 percent of an inoculated Polio virus into digested sludge was observed. From this it was concluded that digested sludge contained a cidal agent not present in raw sludge that efficiently inactivates Poliovirus. This cidal agent was believed to be ammonia.[9]

The anaerobic digestion process's ability to reduce virus populations does not, however, appear to be verifiable as some studies have indicated. One report indicated that both raw and digested sludge contained an uncharged form of ammonia which has the ability to accelerate the heat inactivation of viruses in sludge but, because the anaerobic digestion of sludge typically occurs at pH 7, a pH at which the ammonia is in its nonvirocidal form (ammonium ion), the ammonia present probably contributes little toward the inactivation of viruses during the anaerobic digestion process.[6]

To reduce any possible risk of a disease vector caused by sludge, the U.S. EPA in the Code of Federal Regulations, Title 40, Part 257.3-6, requires that sludge to be applied to the land or incorporated into the soil be treated with a process to significantly reduce pathogens (PSRP) prior to application. Public access to the land would have to be controlled for at least 12 months and grazing by animals whose products are consumed by humans is prevented for at least one month. For sewage sludge to be applied to the land surface and crops for direct human consumption to be grown within 18 months of the application, the sludge would have to be further treated prior to application by a Process to Further Reduce Pathogens (PFRP). The processes which the EPA lists as PSRP as listed in Appendix II of 40 CFR 257 are: aerobic digestion, air drying, anaerobic digestion, composting, lime stabilization, as well as other methods that are acceptable if pathogen and vector attraction of the waste (volatile solids) are reduced to an extent equivalent to the reduction achieved by any of the above methods. Those processes listed by the EPA as PFRP include: composting, heat drying, heat treatment, thermophilic aerobic digestion, and other methods. The following processes must be used in conjunction with a PSRP in order to achieve a reduction in the attraction of disease vectors: beta-ray irradiation, gamma-ray irradiation, pasteurization, and other acceptable methods.

For gamma ray irradiation, the EPA recommends using isotopes such as Co^{60} and Cs^{137} at dosages of at least 1.0 megarad at 20°C. It was found that the 1.0 megarad dose was effective in removing bacterial, parasitic, and fungal pathogens from the sludge, when used as a PFRP.[6,8,10,11] The viral populations were found to be reduced by 3 orders of magnitude in one study where the 1 Mrad dose specified by the EPA was used as a PFRP. In the same study, the highest reduction of bacteria was achieved in an aerated liquid sample of sludge which had been given a 1 Mrad dose.[8] The combined effects of radiation and heat were observed in another study which indicated that a reduced dose of 300 kilorads and an increased temperature of 55°C for 5 minutes with oxygenation effectively reduced bacteria, parasite ova, and viruses. Table I from that study lists various organisms and the amount of reduction found by the different treatments used. The reduction ratio is listed as Log amount, where 1 Log corresponds to a 90 percent reduction and 3 Logs would be 99.9 percent. The D-values for bacterial inactivation from this study are listed in Table II. The concept of D-value as used here is the amount of absorbed energy required to decrease the population by 90 percent or 1 Log. The units of the D-value in Table II are Krad/Log.[6]

From this, bacterial, parasitic, and fungal pathogens should be eliminated by the EPA required PFRP dose of 1 Mrad at 23°C. Even though viruses have been found to be very resistant, this dose when used as a PFRP in conjunction with the required PFRP should eliminate any health risk posed by the viral population in the sludge.[8] The design of the irradiator will, therefore, be based on the need to expose all of the sludge to a total dose of at least one megarad.

TABLE I

Expected Population Reductions by Radiation and Thermoradiation Treatment[8]

Organism	55°C, 0.3 Mrad with O_2, 5 min.	23°C, 1 Mrad with O_2
Coliforms	15 Logs	15 Logs
Fecal Streptoccocci	7 Logs	10 Logs
Salmonellas	15 Logs	15 Logs
Ascaris Ova	15 Logs	15 Logs

TABLE II

D-Values for Bacterial Inactivation*

Temp $^{\circ}$C	Coliforms	Salmonellas	Fecal Streptococci
23	25-30 (8)	26 (13)	130-135 (87)
40	25		129
50	23	19 (11)	109
55	10-15 (4)		86
60	15		70-97 (32)
65	5		46

*The effect of O_2 on D-value is indicated by the numbers in parenthesis. D-values in Kcal/log.
From 6

Experimental Tests

The purpose of this procedure was to determine the radiation dose required to rid anerobically digested sludge of all potential pathogenic micro-organisms.

Background

Pathogens commonly found in sewage sludge include: bacteria, viruses, parasites, and fungi. Listed below are the most common species found in sludge. Also listed are the diseases usually produced by the pathogens. (8)

1) BACTERIA:

Organism:	Disease:
Salmonella sp.	Gastroenteritis
Shigella sp.	Gastroenteritis
Mycobacteria sp.	Tuberculosis
Leptospira sp.	Leptospirosis

2) VIRUSES:

Organism:	Disease:
Enterovirus	Gastroenteritis
Hepatitus A	Infectous Hepatitis
Adenovirus	Respiratory Disease
Reovirus	Respiratory Disease

3) PARACITES:

Organism:	Disease
Ascaris sp.	Ascariasis
Trichuris sp.	Whipworm infection
Entameba Histolytica	Amoebic Dysentery
Giardia lambis	Dysentery
Taenis sp.	Taeniasis

4) FUNGI:

Organism:	Disease
Asperillus fumigatus	Respiratory Disease

DETECTION OF PATHOGENS:

Because of the difficulty in the detection of most pathogens, the less harmful more easily detected Coliform family of bacteria are used as indicators. These Coliforms are present usually in conjunction with the above mentioned more harmful pathogens. In other words, the presence of Coliforms in a sample of sludge suggest the more dangerous pathogens may also be present. An example of a Coliform bacteria is E. coli which is a organism that frequents the lower digestive tract of most all mammals.

In this experimental procedure, the Hach Method for Coliform testing was used. In this method, the sludge sample was added to lauryl tryptose broth, then incubated, and finally checked for gas liberation by means of conventional indicator tubes. The liberation of CO_2 gas in the indicator tubes indicates the presence of Coliforms and thus the potential for other pathogens.

EXPERIMENTAL PROCEDURE:

Anerobically digested sludge (3% solid) was collected and subsequently irradiated at doses ranging from 0 to 1.25 Mrads. An inoculation loop was used to introduce the sludge into the fermentation broth tubes. The fermentation tubes were then incubated at 35° $\pm$0.5 C, and then checked for gas formation at 24 and 48 hours.

RESULTS:

The following table depicts the outcome of each specific Hach test for a certain dose.

DOSE (Mrads):	0	0.15	0.20	0.25	0.30	0.40	0.50	0.75	0.0	1.25
Test Results:	+	+	+	-	-	-	-	-	-	-

NOTE* A = indicates the presence of Coliforms, (presence of CO_2).

It can be observed that the Coliforms were in activated at relatively low doses of about 0.25 Mrad. This value is also reported by other researchers. (12)

PATHOGEN INACTIVATION:

Coliforms are relatively sensitive to radiation as compared to some of the other pathogens found in sludge. Listed below are the D_{10} values for the most common types of pathogens which are known to frequent sludge.(8)

ORGANISM:	D_{10} VALUES (kR):
**E coli*	22
Salmonella sp.	54
Poliovirus	300
Ascaris eggs	50
Aspergillus Fumigatus	50-60

**E. coli* is a Coliform.

Further test were run on sludge samples to further confirm the 0.25-0.3 Mrad value for complete Coliform inactivation. A larger value can be systematically determined for which all potentially harmful viruses will surely be inactivated. At such a value for the dose, the sludge can assuredely be considered safe for agricultural utilization.

SUMMARY:

A comparison of the D_{10} values indicates that the viruses are much less radiosensitive than the Coliforms. The dose required to inactivate the Coliforms does not seem sufficient to completely inactivate the viruses. Thus a higher dose than 0.25 Mrad will probably be necessary. Most references suggest the use of a 1 Mrad dose to ensure sterilization of the Sludge.(13)

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BASIC DESIGN FACTORS

In order to investigate the dose rates attainable, it was necessary first to make general assumptions as to the overall design of the facility. A number of circumstances, conditions, and arrangements were assumed or selected in order to provide a design to be evaluated. The following design factors are therefore preliminary and subject to modification as a final design evolves in the general concept of a three-pass system in which sludge is conveyed over, between, and under two rows of cylindrical sources.

The form and quantity of material to be treated is a fundamental matter, as is the total dose of radiation that is to be administered. The configuration of the source and the conveyor system must be coordinated, and shielding must be provided during operation and when the sources are retracted. A safe system for loading and unloading of sources is mandatory. These and other matters are discussed in more detail below. It is assumed that the initial installation of an irradiator will be at an existing wastewater treatment plant and some accommodation of design may be required to fit conditions as they now exist.

The source material is in the form of cesium-137 incorporated in cast glass cylinders that are encapsulated in stainless steel. At the present time this process is still under investigation and the source parameters used in the present study must be considered preliminary in nature. Table III contains data on two source forms under development.

A fairly rough calculation will show that it is impractical to use sources of Type I for irradiation of any significant volumes of material that require dose values of the order of a megarad with residence times of less than a day. Consequently, the design work described below has assumed the availability of Type II sources in single cylinders or in cylinder arrays up to 2 meters in length.

TABLE III

POTENTIAL SRP CESIUM SOURCES

	Source #1	Source #2
Cs-137 Content, Ci/kg	190	5800
Limiting Factor	20% K_2	15% Cs_2O
Canister Size Diameter (cm)	61	18
Height (cm)	300	adjustable
Glass Density g/cc	2.7	2.8
Dose Rate at Surface (rads/hr)	20,000	400,000

State of Sludge to be Irradiated

Three possible conditions of sludge are: 1) digester effluent, solids content 3-4%; 2) dewatered sludge, solids 15-20%; 3) dried sludge, solids 35-40% or higher. The dewatered sludge has a consistency similar to moist clay; a thin sheet will stand on edge several inches high. It sticks to itself and other materials to the extent that removal from, say, a metal trough requires a positive pushing action. Sludge in this condition is typically moved about the plant on conveyor belts equipped with scrapers at the discharge end. The moist material is difficult to handle and does not appear to be a practical form for spreading for agricultural use. The irradiation of sludge in this condition has been considered only because it is the form most commonly found in the processing sequence of wastewater treatment plants. The disadvantages of handling seem to far outweigh the costs of drying, and the dewatered condition was, therefore, eliminated from consideration.

The utilization of digester effluent for agricultural purposes is a well recognized technology that is being exploited in some areas. Equipment as simple as a truck with a tank and sprinkling nozzle will serve to distribute the material on the surface of the ground. A more sophisticated system consists of a large vehicle with low-pressure tires that can move readily over soft ground with a large reservoir of sludge. An example of such equipment is shown in Figure 2. The liquid sludge is injected at a selected depth below the surface with a series of plows at the rear of the vehicle. In the usual circumstances the application device is placed on site and served by one or more tank trucks bringing sludge from the treatment plant. This procedure is particularly attractive where water is scarce, but transport of large amounts of water is costly. The major disadvantages of using the liquid effluent are the high initial investment in equipment, but more importantly, the limited area that can be served on an economically feasible basis.

From the standpoint of irradiation, the liquid form is undesirable because most of the energy would be expended on the water, and the practical use of radiation would be limited to those few treatment plants with a large market situated within a few miles.

Dried sludge can be handled readily both at the treatment plant and in subsequent distribution. Transportation costs are minimized whether the product is bagged or in bulk; this greatly increases the size of the practical market area. The obstacle to routinely producing dried sludge at all treatment plants is cost. Process and equipment selection for existing waste treatment plants was presumably based on engineering principles appropriate to the situation, but possible subsequent addition of an irradiation step was not a consideration. Consequently the output of many plants would require modification to obtain material suitable for irradiation.

Usual treatment sequences provide a liquid/solids separation step that increases the solids content, thereby reducing the volume of sludge to be handled. Several different processes are in common use and are shown in

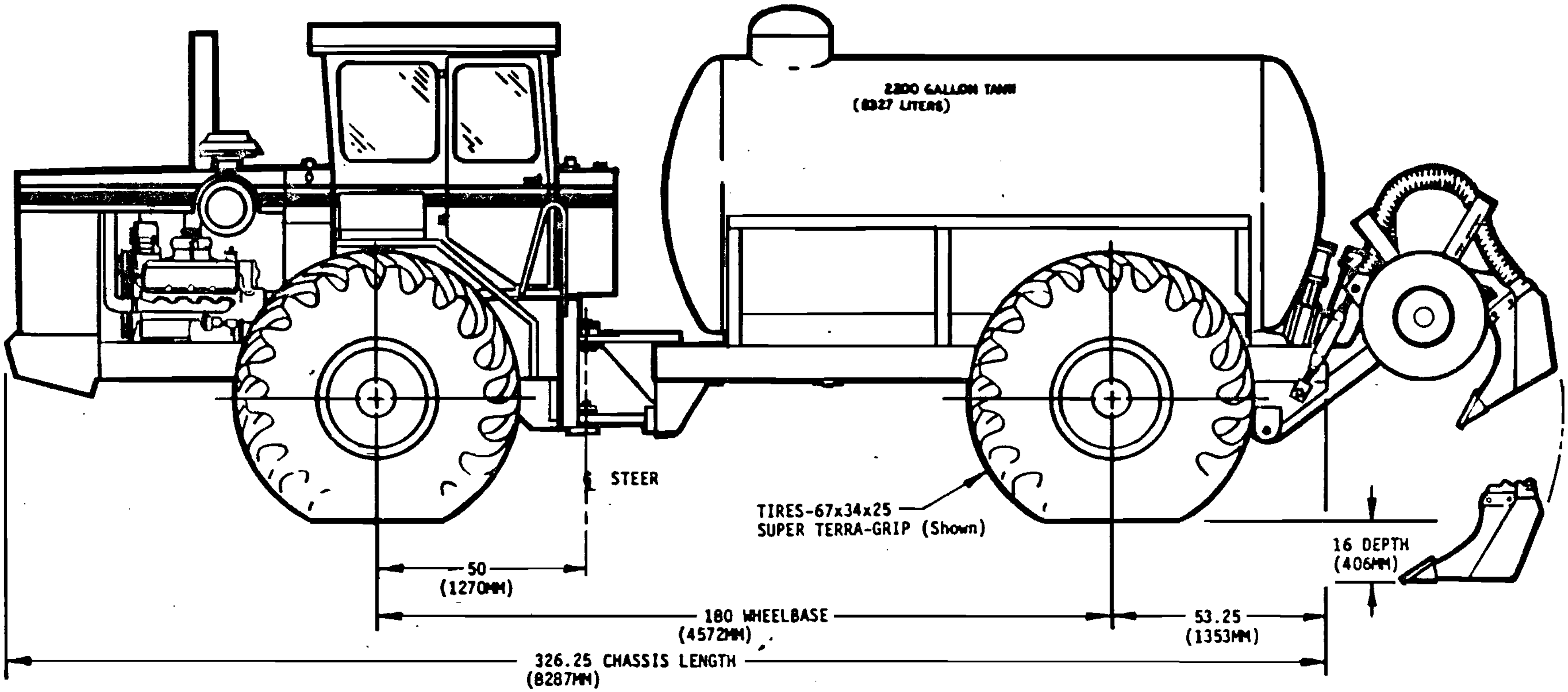


Fig. 2 Sludge applicator

Figure 3 which also includes typical solids content of the sludge at various stages. Sand drying beds are generally useful only for small communities as considerable area is required and appreciable manual labor is needed to remove the dried residue. The effectiveness of the process is weather dependent. Under hot, dry conditions, a batch of sludge may be ready for removal in a couple of weeks, but sludge placed on a drying bed in the fall of the year may not be sufficiently dry until the following spring. The general trend today appears to be away from drying beds, but the process does reduce the level of pathogens present and provides a product that can be easily handled.

Vacuum filters and centrifuges have been traditionally used for may years, but belt presses are gaining in popularity. All of these machines generally require the use of a chemical additive. Ferric chloride and lime may be used with vacuum filters or a polymer may be used with any of them. The small quantities of additives required seem unlikely to have any significant influence on the use of the sludge. The end product of each of these processes is quite similar and would require additional drying before irradiation.

Filter presses offer a rapid process for producing high solids output, but operation is a batch process that requires manual labor in the opening and closing of the press at each cycle. This type of press has not been widely used in sludge processing, although the output may be suitable for subsequent handling in agricultural applications.

Whatever dewatering process is used, the resulting material can be further dried by exposure to the atmosphere. It may also be composted, a process that does not work very well with freshly dewatered sludge. Sawdust, rice hulls, or previously dried sludge may be added, however, to yield a mass porous enough to allow air penetration and the composting process to proceed. The sludge/filter mixture is piled in rows which are straddled by a machine that mixes and aerates as it passes. Heating occurs during the composting cycle that may be sufficiently high to kill the pathogenic organisms present, but there is no assurance that the required temperature

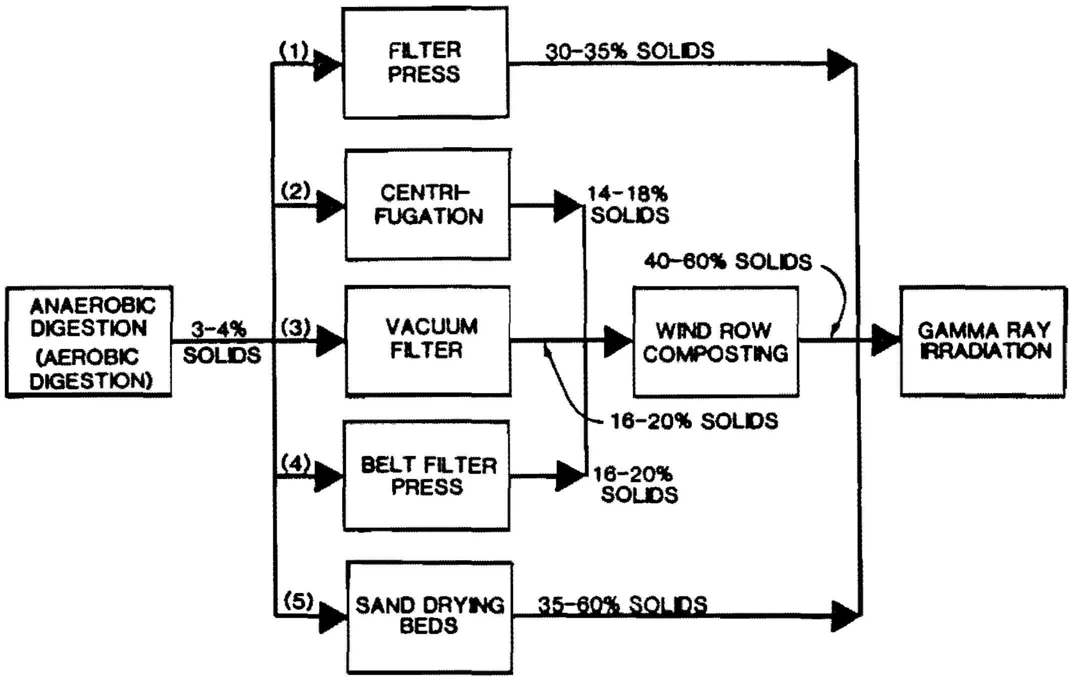


Fig. 3 Digested sludge dewatering alternatives

is obtained uniformly. A useful brown crumbly product results after several turnings and the passage of sufficient time, but the process is subject to the vagaries of the weather. As a continuous supply of dried sludge is needed to optimize operation of an irradiator, interruptions could be overcome by maintaining a stockpile of product.

Other drying processes that provide a quick, positive operation all require significant energy inputs, most commonly natural gas or oil. Digester gas may be used as available, and in at least one instance wood chips provide the fuel. The high temperature normally involved in forced drying would generally provide an environment for the destruction of pathogenic (and other) organisms to the extent that irradiation would no longer be required. For this reason it is believed that air dried or composted sludge would be the best choice of feedstock for the irradiator.

Conveyor System

The conveyor system provides a means for getting sludge into and out of the irradiation field. It also offers a convenient mechanism for regulating the total dose through control of the conveyor speed. The absorbed dose in a constant radiation field is directly proportional to the time of exposure and is, therefore, inversely proportional to the speed at which the sludge passes through the radiation zone.

The conveyor system must be arranged to minimize the distance between the sludge and the radiation source; the exponential fall-off of dose rate with increasing distance from the relatively low-specific-activity SRP sources makes this spacing a very important matter. Because of the spacing consideration, the best geometry for the sludge is a thin sheet, with width of the sheet determined by the length of the source cylinders.

Several types of conveyors can provide wide, shallow streams of bulk material, each with its own advantages and disadvantages.

Belt conveyors are widely used for many purposes, but any elastomeric material is subject to deterioration by gamma radiation and is not suitable for use in an irradiator. Flexible metal belts are somewhat more expensive, but have the decided advantage of being thin, and therefore requiring a minimum space between the source and the product both in the feed direction and in the return part of the cycle.

Vibrating or oscillating conveyors are also used for bulk materials, but are designed for transport rates much higher than would be required in an irradiator. It is believed that precise speed control would be difficult with that type of equipment.

A positive pushing action can be achieved by use of transverse flights attached to a dual chain drive. If enclosed in a thin metal conduit, this arrangement would keep the sludge within the desired boundaries and preserve the vertical height of the sludge. This orientation is significant, as it is necessary to assume that the top layer of sludge, which receives the lesser dose when entering above the sources also receives the greater dose when passing under the sources. A continuously variable speed device would provide good control of the conveyor speed. This arrangement has, therefore been chosen, with details of flight spacing and other mechanical aspects to be specified in the final design.

DOSE ESTIMATES

To optimize the irradiator configuration, the design parameters of greatest concern are maximum and minimum dose obtained, target cross section, dose uniformity, and source utilization (1,2). In view of the state of the target material and the relative weakness of the sources, it is important to move the target material horizontally closely to the source cylinders, even though this does not yield the best value for dose uniformity. To improve source utilization a three-pass system was chosen, such that the target material receives 50% of the dose when passing between two rows of sources and 25% each when passing above the upper row and close below the lower one.

For reasons of source support and to provide a fail-safe retraction system, the target conveyors are oriented normal to the source cylinder axes. Near the source surfaces this results in a rather fluctuating radiation exposure as the target travels. To calculate this dose a computer program was developed, which is presented in Appendix A. This program differs radically from other computer programs of this type (1), which usually assume that the source is a thin, flat plaque of a given specific activity and the target is far enough away that surface inhomogeneities are important. In the present case, the sludge was exposed to an extended, ribbed source configuration and the dose calculation had to integrate the contributions of both the nearest and the more distant source cylinders to a finite thickness of target material. Appendix A contains a more detailed description of the code developed.

An investigation has been made of the dose rates achievable with several spacings and arrangements of sources. The highest practical rates appear to be those existing between two rows of sources, although the lower rates on the outer sides would also be utilized to increase the overall source utilization. Numerical solutions have been obtained for an arrangement (sketched in Figures 4 and 5) of a 20 cm thick layer of sludge passing between sources with a minimum surface to surface spacing of 30 cm. This

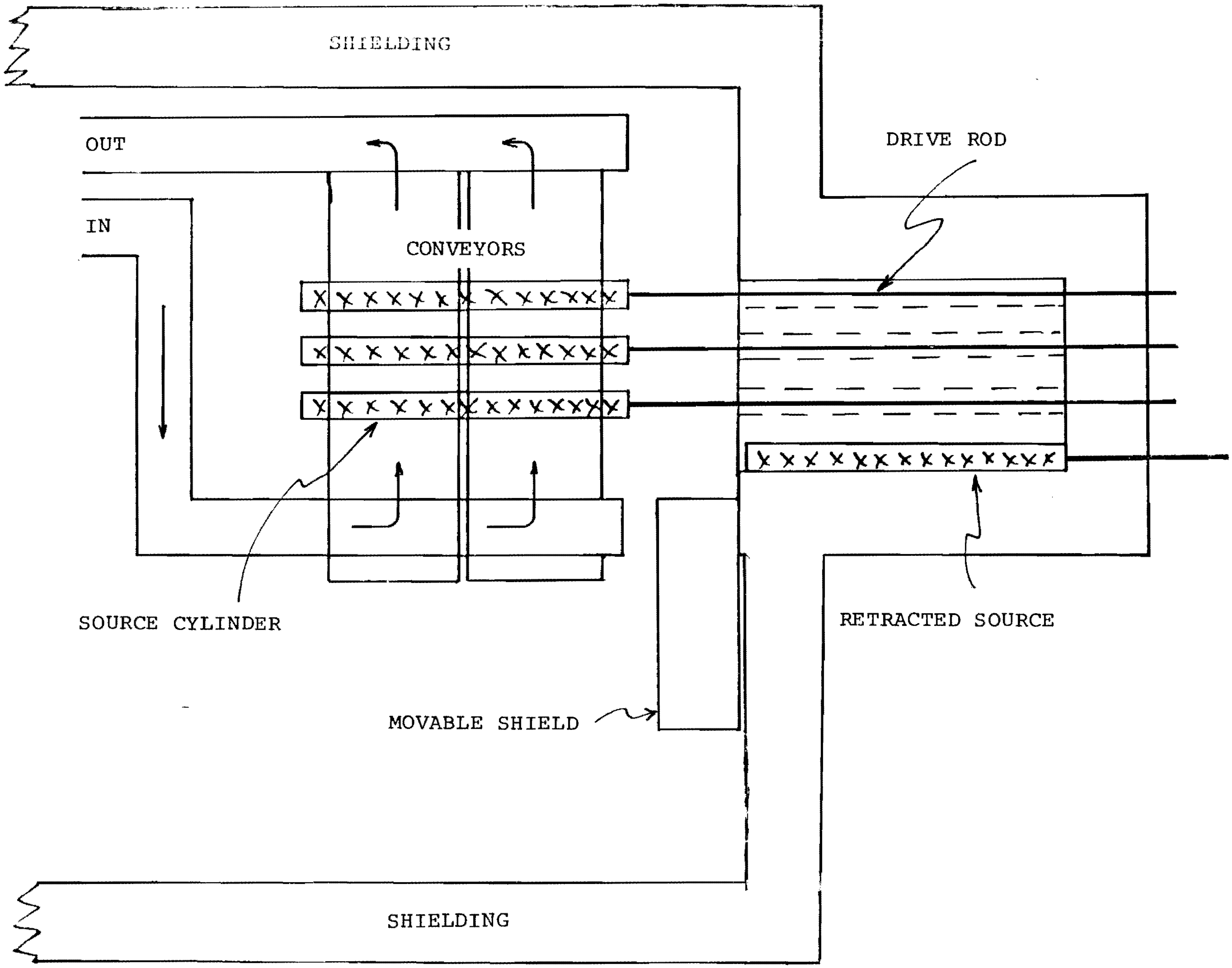


Fig. 4 Plan of irradiator

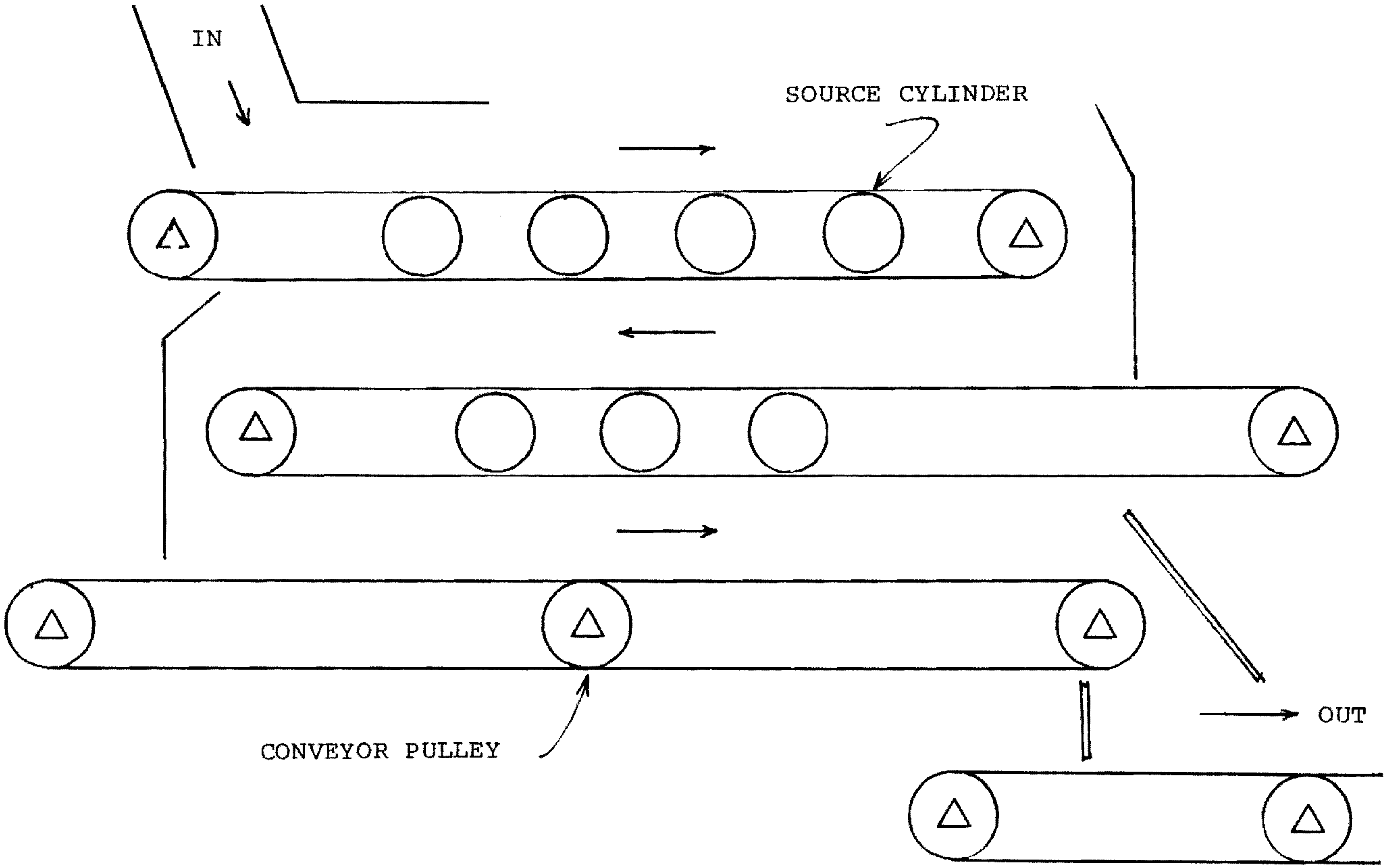


Fig. 5 Sectional view of irradiator

allows for a 20 cm. thickness of sludge plus a 5 cm clearance above and below to provide for the conveyor mechanism. An array of seven sources on one side and six sources on the other side, offset by a cylinder radius, produced the calculated dose rates shown in Figures 6-10. Figure 4 shows the dose rates at the surface of the sludge which is 5 cm minimum from the surface of the sources on the side with seven sources. This path is along the center line of sources 40 cm. in length. The maxima occur at the center of each source, which is the point of closest approach.

A considerable increase in dose rate occurs as one passes from the center of the first source to the center of the second. A small build-up is seen between the second and third, but there is little additional effect thereafter until the other end of the array is approached. It is concluded that in this type of configuration the addition of more sources would not increase the dose rate, but would, of course, enlarge the volume of the maximum rate zone. No allowance was made for scattering buildup in the sources or the target volume.

Figure 7 depicts the dose rates along the path of movement at the center of the sludge layer, (10 cm into the sludge) which is 15 cm minimum from the surface of the sources. This path is also along the center line of the 40 cm source cylinders. The sharp maxima existing at the surface have vanished and a smooth curve results. The maximum on this plot is about 0.84 MR which compares with about 2.0 MR at the surface. The dose rate at the far side of the sludge layer, i.e., closest to the row of six sources, is shown in Figure 8. The maximum calculated dose on this surface, 2.03×10^6 R/hr, is not significantly different from that on the opposite (7-source) surface, 2.07×10^6 R/hr, demonstrating, as would be expected, that the field is symmetrical about the center plane. To ensure that all the sludge receives at least the minimum prescribed dose, calculations are based on the zone of lowest dose rate,which is in the center plane between the sources. However, the dose rate also diminishes near the end of the source cylinders. It is therefore believed advisable to provide a slight overhang of the sources beyond the edge of the sludge. The field at the center of the sludge layer 5 cm and 10cm from the end of the 40 cm long sources was calculated with the resulting curves shown in Figures 9 and 10, respectively.

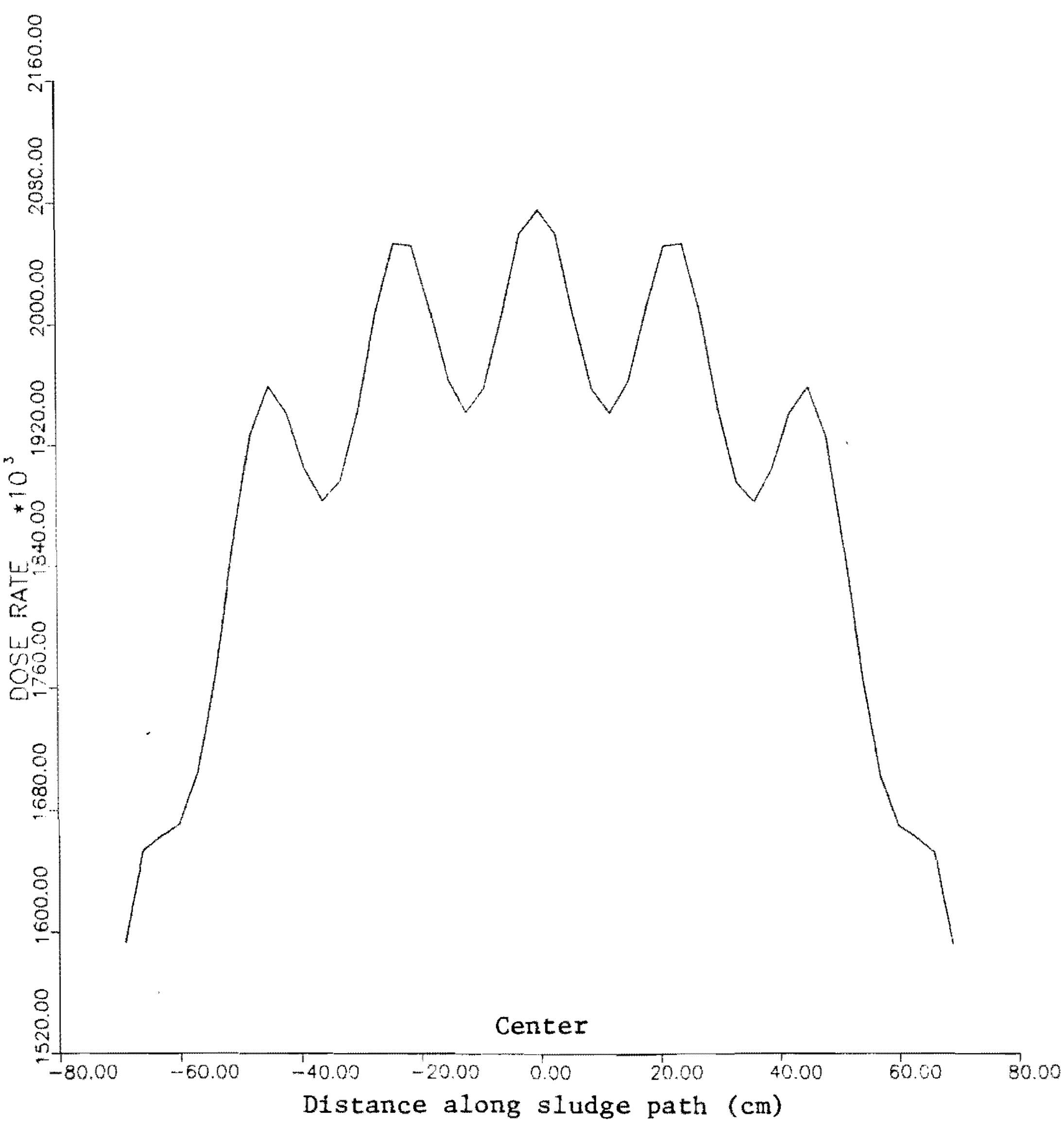


Fig. 5 Dose rates at surface (7 source side) of sludge moving along center line of sources 40 cm. long.

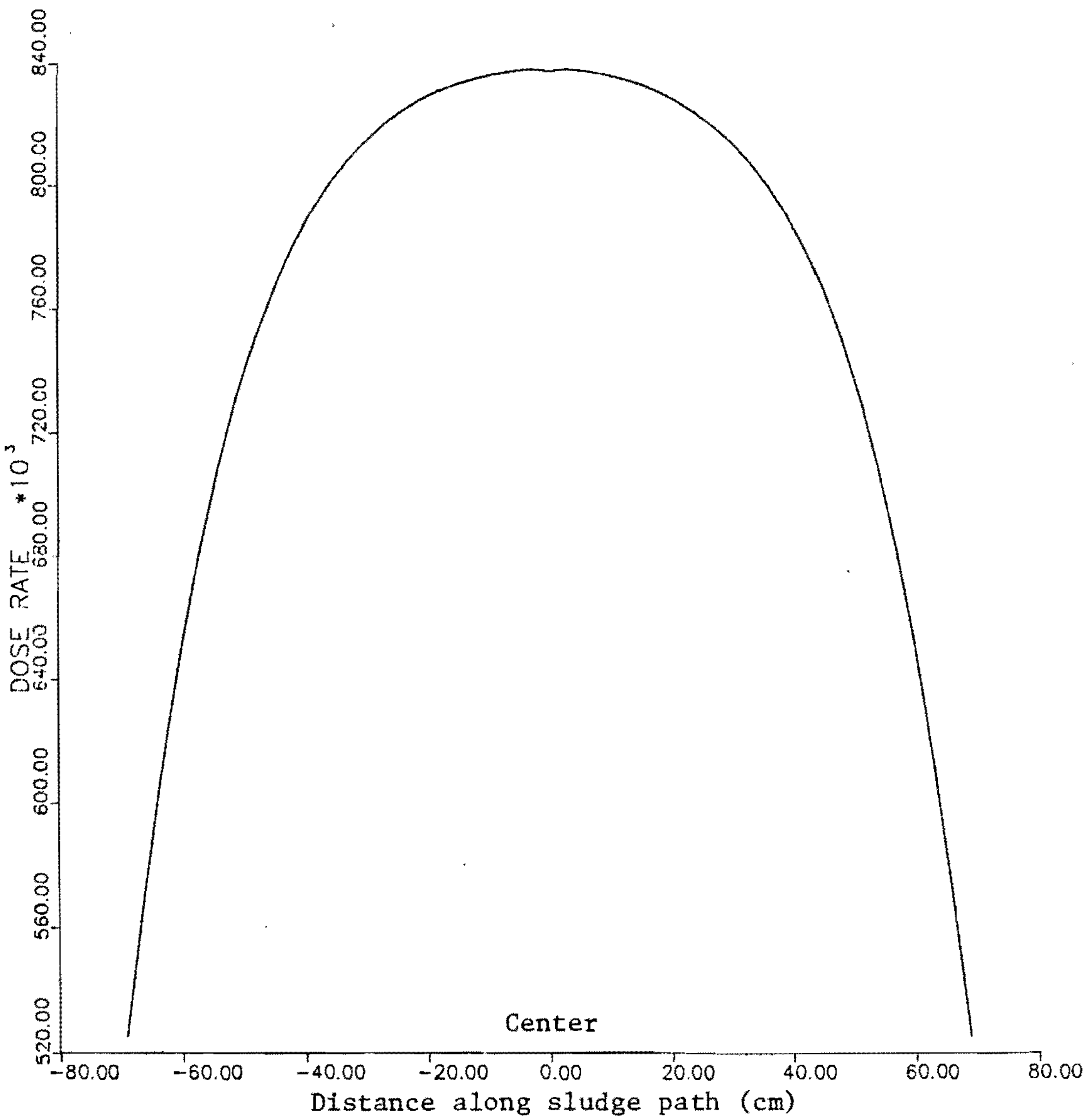


Fig. 7 Dose rates in the center plane of sludge moving along center line of sources 40 cm. long.

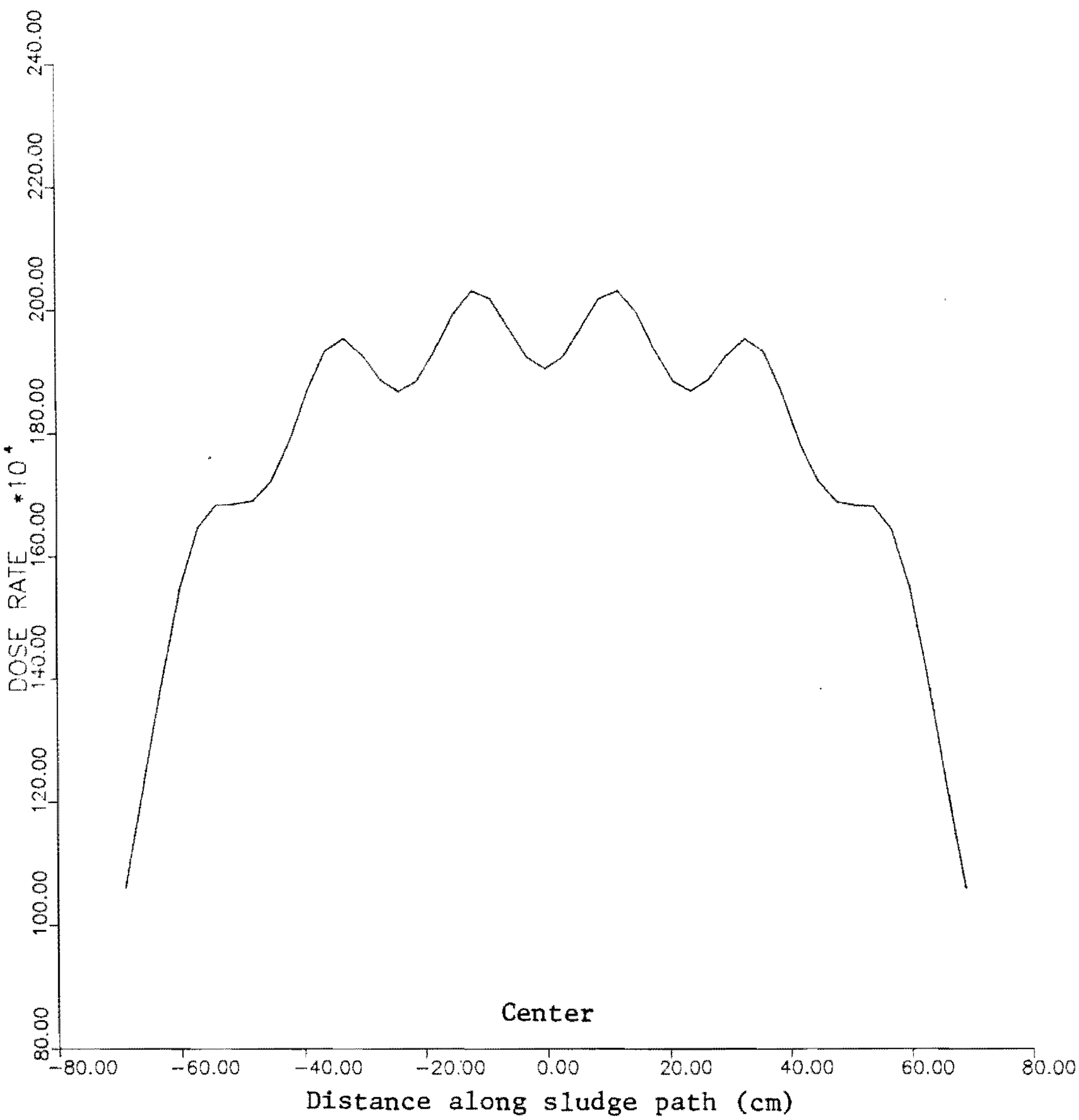


Fig. 8 Dose rates at surface (6 source side) of sludge moving along center line of sources 40 cm. long.

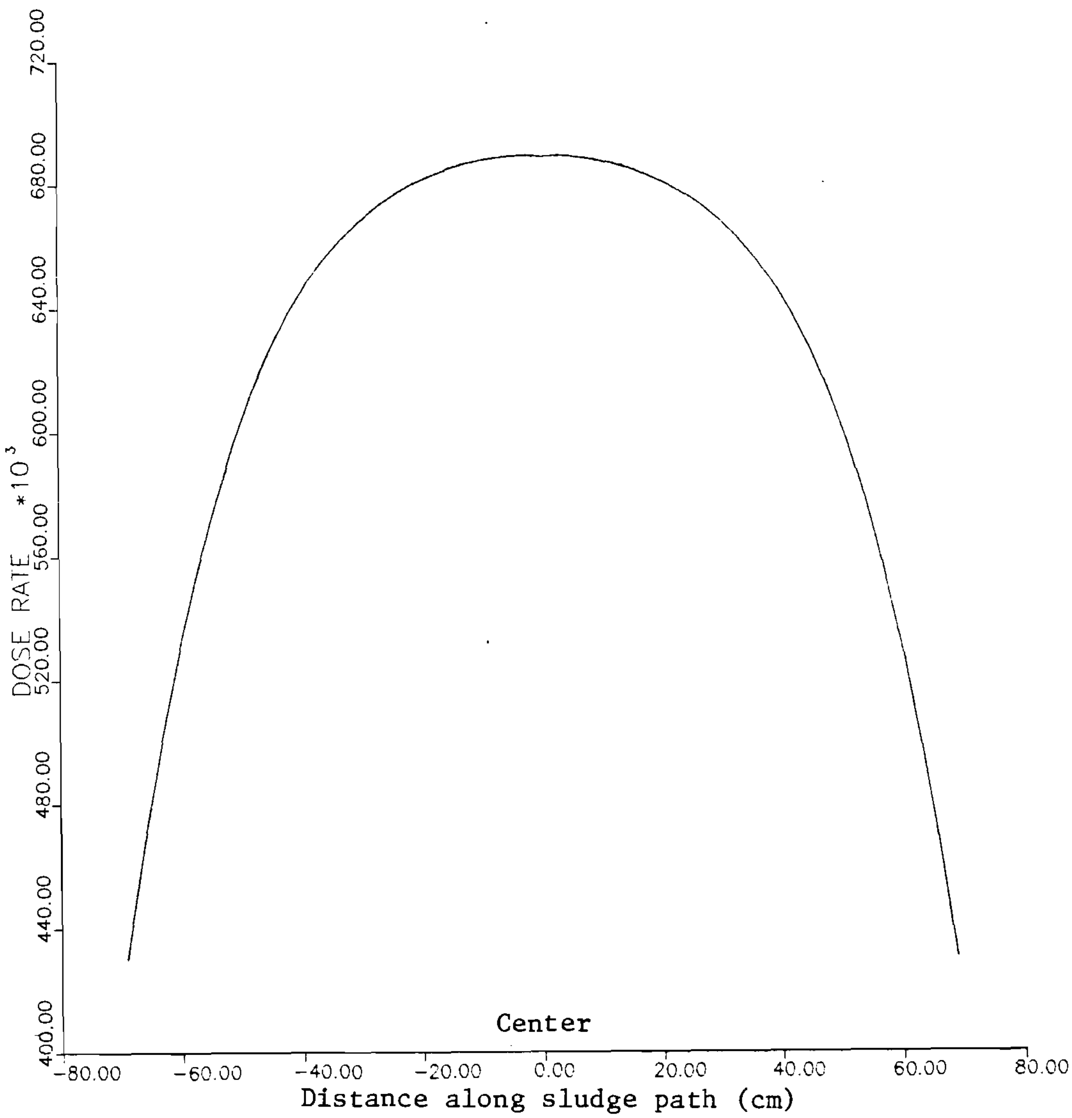


Fig. 9 Dose rates in the center plane of sludge moving along 5 cm. from ends of 40 cm. sources.

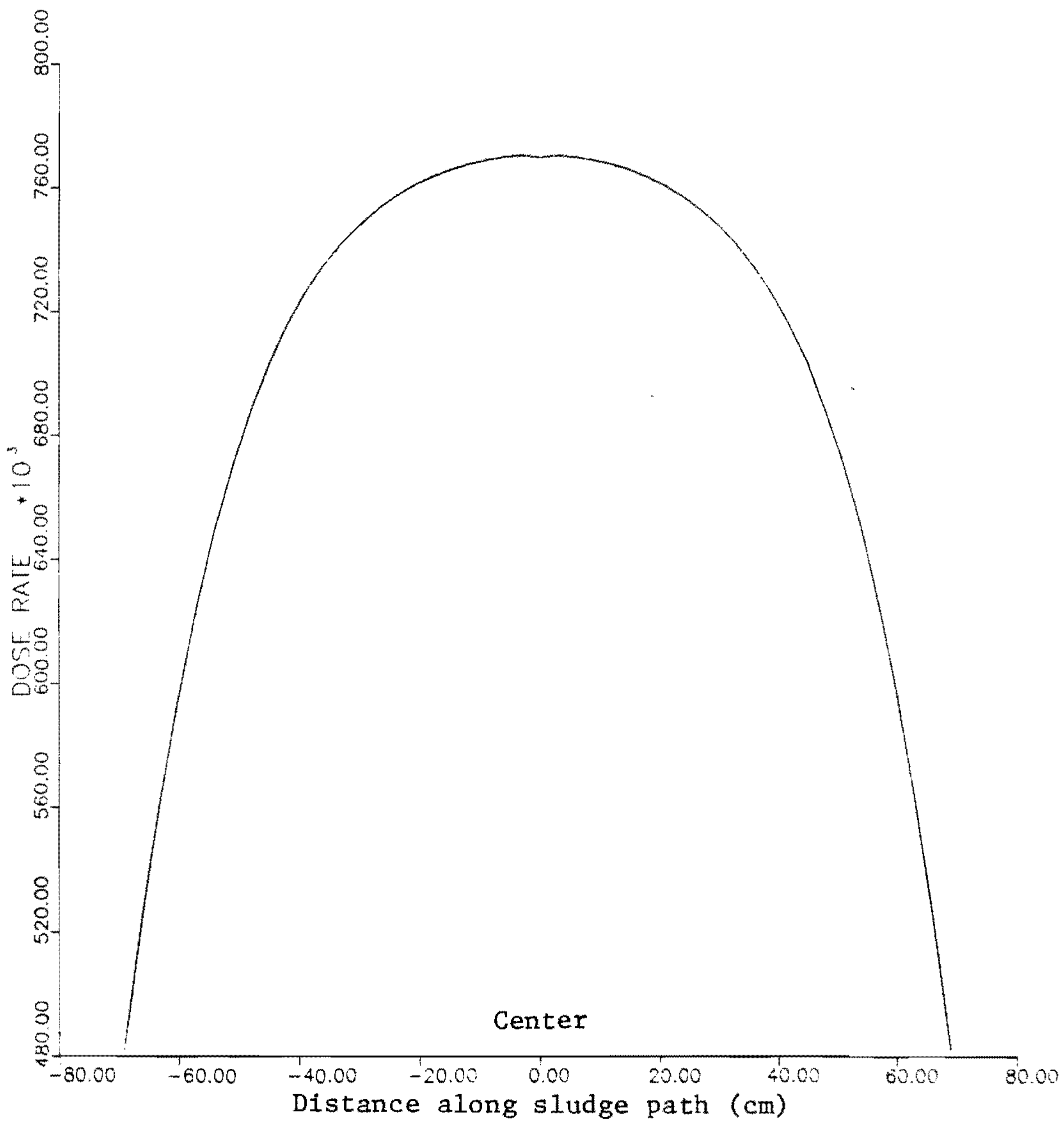


Fig. 10 Dose rates in the center plane of sludge moving along 10 cm. from ends of 40 cm. sources.

Integration of the curve of Figure 9 shows that within the 138 cm span, the average dose is about 6.2×10^5 R/hr. Half of the required dose would therefore be delivered in a uniform transit of 48 minutes. One-fourth of the dose would be delivered on the approach path above one row of sources, and another one-fourth below the other row as the sludge moves in an S-shaped path above, between, and below the two rows of sources.

The capacity of this system was calculated on the assumption of a width of 200 cm (probably two conveyor systems side by side), a sludge thickness of 20 cm., and a radiation zone length of 140 cm. This gives a volume rate of 0.7 m^3/hr. Based on a sludge density of 0.5 g/cc this calculates to 350 kg/hr or 9.24 tons/day. This does not take into account any dose rate increase caused by lengthening the sources from 40 cm to 200 cm..

The total amount of radioactivity in this arrangement of thirteen sources would be about 12 Megacuries, based on a specific activity of 16-17 curies per cc. The heat generated per source cylinder is calculated to be about four kilowatts and provision for its dissipation may be required. One possible cooling arrangement could include a hole through the center of each source cylinder. This would be cast into the cylinder during manufacture and provide for air or water cooling. Alternatively, air blown across the sources may be used to help predry the sludge.

A second evaluation of source configuration using seven cylinders was made, including as a variable the spacing between adjacent cylinders. The array consisted of a row of four sources on one side with three sources opposite, and centered on the spaces between the four. A spacing of one cylinder diameter, 18 cm, was found to provide a uniform field in the center plane of the sludge 5 cm from the end of the source cylinders. The dose rates along the length of the sludge path are shown in Fig. 11. Integration of these dose rates gives an average value of 2.93×10^5 rads/hr, which is the minimum dose rate to which any increment of sludge would be exposed if it moved along the outer edge of the sludge mass, in a plane centered between the sources. Using a width of 200 cm, depth of 20 cm, and a length of 150 cm, the volume of sludge in the central region is 0.6 m^3. This provides a daily capacity of 4.6 tons/day. This figure does not include the lesser amounts of radiation that would be received as the

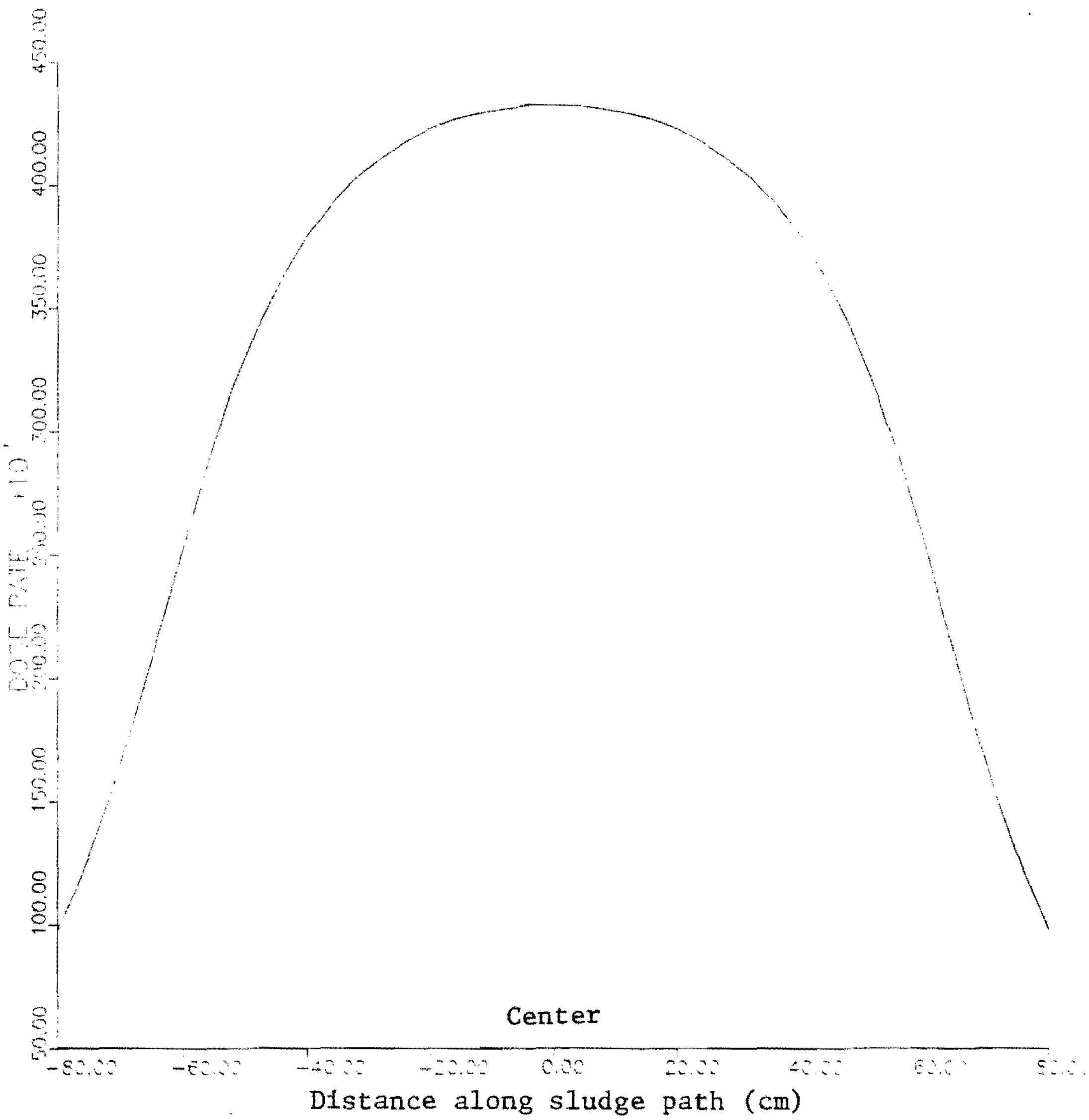


Fig. 11 Dose rates in the center plane of sludge moving along 5 cm. from ends of 40 cm. sources in a source array of 7 source cylinders total.

sludge enters and leaves the main radiation zones, nor that received in the areas around the conveyor drive and idler rolls, where the direction of movement is being reversed. The stated capacity may therefore be considered a conservative minimum.

It should also be noted that the calculated capacity is proportional to the density of the sludge. The dose rate is not very sensitive to moderate changes in the water content of the sludge. The addition of some water would, therefore, increase the theoretical capacity disproportionally to the decrease in delivered dose.

THE IRRADIATOR FACILITY

While there has not been time within the confines of the present project to do a detailed engineering design of the proposed facility, Figure 4 presents a general outline of the conceptual design. The shielding requirements and design of the entrance maze will depend on the total source strength and are only presented in rough outline here. Since it is assumed that the facility would be located at the site of an existing sewage treatment plant and be integrated into its operation, the loading and unloading systems should be as simple as possible and demand a minimum of additional labor. The labor force would not ordinarily be considered occupational radiation workers, though it would be desirable to provide all personnel normally on site with individual personnel monitors (TLD). Several independently operating interlocks must be provided to prevent accidental entry into the facility and to ensure safe shut-down and source withdrawal in case of interlock failure or earthquakes.

Sources

The sources consist of stainless-steel clad glass cylinders about 18 cm in diameter and for the present purpose were assumed to be about 2m (6.6 ft) long. Whereas in "conventional" irradiators the sources are arranged vertically and, typically, recede into a storage pool when not use (1), in this case the nature of the target material favored horizontal placement of the sources. This leads to an arrangement where the sources run on thin rails or metal rollers, at a slight upward slope from the shield block to ease rapid return in case of an emergency. Because of the length of the sources a positive chain drive or push block arrangement is suggested instead of the pneumatic system favored for shorter or lighter sources.

Each source would be retracted into its own cylindrical shield hole, with a shielding plug either attached to the source cylinder itself or hinged above each shield position to drop into place when the source is retracted. Loading of the sources from the shipping casks would also be horizontal through removable shield ports.

Shielding

Though detailed shielding calculations have not been done so far, a general outline of requirements can be provided. The shield consists of three components: the source storage block, the facility building itself, and the entrance maze.

The size of the storage block will depend on the number of source cylinders used, e.g. 7-13. The sources will be stored in two rows about 18 cm apart, in cylindrical holes about 2.5 m long to allow for the shield plug and for push rod attachment. The holes will be oversize to provide for a rail and cradle arrangement or for idle rollers, but also to permit air circulation for source cooling. Wall thickness would be of the order of 6-7 ft. of concrete or earth in concrete walls.

To save on shielding costs the building would be excavated into the ground so that the upper source row would be a few feet below ground level. This will necessitate a sloping ramp behind the storage blocks to permit access to the trucks carrying the source shipping casks. A mobile crane would be used to help unload the casks and remove and replace the shield block wall plugs.

The main radiation cell would similarly require 6-7 ft. of concrete or earth shielding in the side walls and the roof. Since the active irradiator area is only about 7 ft. x 7 ft., the main space inside the facility will be taken up by the conveyor system and no difficulty is foreseen in having an unsupported reinforced concrete roof over an area of the order of 16 x 16 ft.

To minimize scattered radiation the entrance maze will require at least three passage sections each about 4 ft. in width to accommodate the conveyors and leave some access space. This means wall thicknesses of the order of 3 ft. between each passage segment with some extra reinforcement at the turning end. This will be aided to some extent by the need to ramp the maze so that the lower conveyor will emerge at a convenient height above ground level for truck loading.

Conveyors

As indicated in an earlier section, segmented thin metal conveyors are preferred within the radiation facility to minimize radiation damage. These will have to be remotely, but positively, driven by chain drives, as the ozone concentration in the radiation cell militates against any electrical equipment there. The inward and outward conveyors would use the maze pathway at different heights above the floor, with a cross shift of material at each bend in the maze. This is one of the more expensive features of the system that deserves more study of alternatives.

Similarly the three-pass system around the source cylinders requires two transfers to successive levels and the conveyors will have to be designed carefully to minimize spilling or blockage of the sludge. Provision has to be made also for periodic cleaning of the conveyor by means of wire brushes and an air suction system to prevent sludge accumulation anywhere within the radiation cell.

Safety Systems

As mentioned above, provision must be made for automatic retraction of the sources into the shielding block, whenever the interlocks are tripped, in case of earthquakes, or any failure of the conveyor system. A standby power source must be provided to retract the sources into the shielding block and to main the interlock system in case of main power failure. At least two access control systems are suggested, e.g. a photo-electric system and an infrared or sonic beam to detect improper access. Because of ozone generation, the radiation cell must be positively ventilated at all times and all electrical switches, relays and contacts should be located outside the radiation area. Closed-circuit cameras are desirable to monitor the process. Adequate drainage must be provided to prevent flooding of the facility at any time.

Because of the long half-life of the sources, source replacement would not be required more than once every 15-20 years, which compares with a theoretical life for the treatment plant of 50-60 yr. However, some provision would have to be made for decommissioning the facility and for disposal or re-use of the sources.

DISCUSSION OF RESULTS

The objective of this work has been to explore the feasibility of utilizing the vitrified cesium-137 waste form produced by the Savannah River Plant vitrification process for the radiation sterilization fo sewage sludge. Early on in the project it was determined that only the higher specific activity source material would be considered adequate for the purpose, since the dose rate available for the more dilute waste even on contact could not provide a sufficient dose in any acceptable time frame.

After careful consideration of all alternatives, wet sludge, dewatered sludge and dried sludge, the latter was selected as the target material for the final design. In wet sludge, too much of the radiation is uselessly absorbed in water and dewatered sludge is very difficult to handle on a remotely operated conveyor system. This leaves dried sludge, despite the higher cost of drying, although some of the heat for drying could be derived from the radioactive sources. On the other hand, dried sludge is more easily package for commercial sale.

After some initial problems, the computer model developed by DY Suh worked well and resulted in a number of dose profiles that illustrate the problems of having to run the target material 5 cm from the source surfaces. Using 13 source cylinders an average dose of 0.6 MR can be obtained along the centerline of the target, with about double that in the surface layer for a capacity of 9.24 tons per day. For 2m long cylinders this represents a total source strength of 12 megacuries, which is judged to be too high for a single installation. For this reason an alternative source array of 6 magacuries in 7 cylinders spaced one diameter apart was considered. This roughly halves the dose rate and hence the plant capacity, but probably represents a more manageable source strength from the point of view of the shielding required, the source shipment and source storage, and may still be an acceptable dose level (3).

The work described here has shown the general feasibility of using the higher specific activity waste form as a source for sludge irradiation. Compared with the high specific activity cobalt-60 sources considered in earlier approaches (1), it is evident that the use of vritrified waste sources calls for rather bulky sources and more total activity. The economics of this approach to a large extent depend on the cost assigned to the waste forms. If it is offset against the alternative of emplacing the waste into a high-cost, high-level waste repository, the usage cost in an irradiator may well be a negative contribution, i.e. a net benefit to the waste disposal process. This factor should encourage consideration of such irradiators for other applications, such as deinfestation of food where a lower dose and higher capacity would be desired.

References

1. B. Manowitz, R.H. Bretton, L. Galanter and F.X. Rizzo, Computational Methods of Gamma Irradiator Design. Rept. BNL-889, Brookhaven National Laboratory, 1964.

2. G.G. Eichholz, Radioisotope Engineering. Marcel Dekker, New York, 1972.

3. A. Suess and T. Lessel. Radiation Treatment of Sewage Sludge - Experience with an operating pilot plant. Radn. Physics Chem. 9, 353-370 (1977)

APPENDIX A

DESCRIPTION OF THE CYLPLN COMPUTER PROGRAM

Introduction

A computer program had to be developed which could calculate the dose received in a rectangular sludge target volume from one or more cylindrical radiation sources of appreciable extent in close proximity.

Program CYLPLN was developed for this purpose. It calculates radiation exposure rate at a point in a plane target. Radiations are emitted in one or multiple cylindrical sources.

Radioactive materials are distributed uniformly in the cylindrical sources. Radiations are attenuated in the source medium, air and the target medium.

These three media are assumed to be purely absorbing media.

The program can calculate the exposure rates at multiple points at the same time. Then they are plotted with the position as abscissa and exposure rate as the orginate.

COMPUTER AND LANGUAGE

Computer:	Cyber 855
Operating System:	NOS 2.1
Language:	FORTRAN 5

Introduction

The radiation generated in the source travels first in the source medium where it is attenuated. After departure from the source it travels in air until it reaches the target. In this program the ranges in the source, air, and the target are calculated. With each range and absorption cross-section, the attenuation rate in each medium can be calculated.

DESCRIPTION OF THE MATHEMATICAL MODEL

To evaluate the total effect of a cylindrical source, the cylinder is divided into (760 or (760/2) small volumes.

A three-dimensional linear equation can be written between the center of a small volume and the point of interest in the target.

The range in the target is the distance between the target point of interest and the cross point in which the three dimensional line meets the surface of the target.

The pathway in the source is the distance between the center of a small volume and the cross point in which to line meets the surface of the cylinder.

The path length in air is the distance between two cross points.

The contributions of all small volumes are added up and the sum is the exposure rate from a cylindrical source.

In the case of multiple sources, the effect of each source is summed.

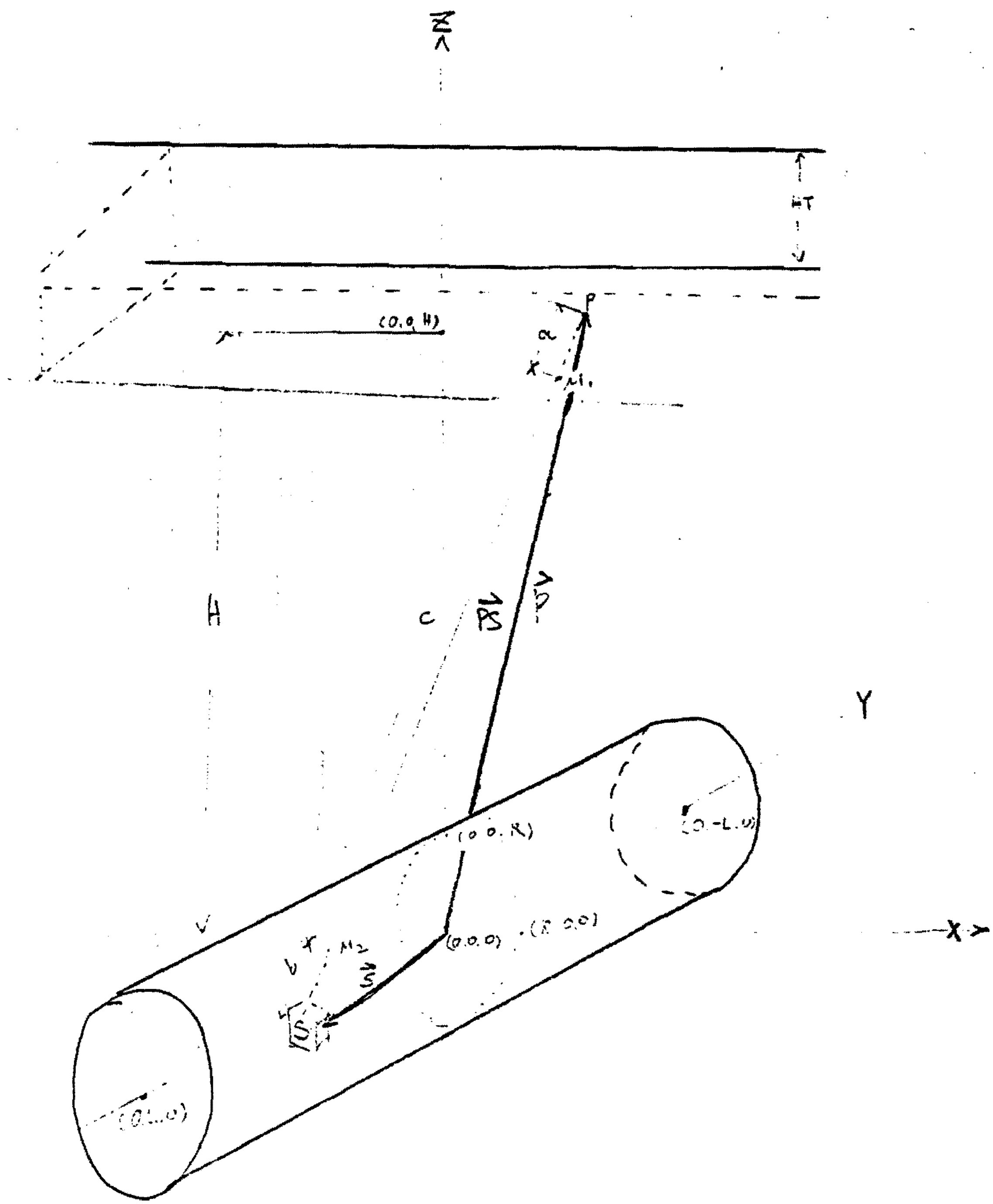
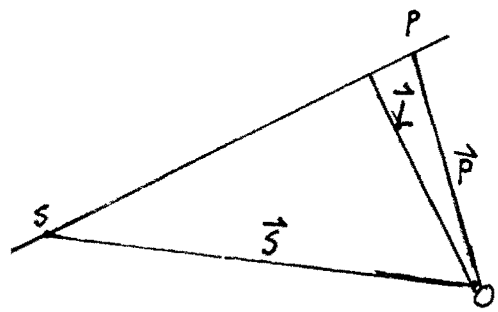


Fig. 13. Source - Target Geometry.

3 DIMENSIONAL LINE EQUATION



$\overrightarrow{PS} = (\vec{P} - \vec{S})$

$\vec{L} = \vec{S} = C\,(\vec{P}-\vec{S})$

where C is coefficient.

$$x = A(x)\,Z = b_x$$

$$y = A(y)\,X = b_y \qquad (1)$$

$$Z = A(z)\,Y = b_z$$

$$\vec{P} = (x_p, y_p, z_p), \quad \vec{S} = (x_s, y_s, z_s)$$

where $A_y = \dfrac{y_p - y_s}{x_p - x_s}$ $\qquad b_y = \dfrac{x_p y_s - y_p x_s}{x_p - x_s}$

$A_z = \dfrac{z_p - z_s}{y_p - y_s}$ $\qquad b_z = \dfrac{y_p z_s - z_p y_s}{y_p - y_s}$

$A_x = \dfrac{x_p - x_s}{z_p - z_s}$ $\qquad b_x = \dfrac{z_p x_s - z_s x_p}{z_p - z_s}$

THE EQUATION OF CYLINDER SURFACE

$$X^2 = Z^2 = R^2 \qquad (2)$$

$$-L < y < L$$

THE EQUATION OF SURFACE OF TARGET

TOP SURFACE $Z = H$ $\qquad (3)$

$$-T/2 < Y < T/2$$

SIDE SURFACE $Y = -\dfrac{T}{2}$ or $\dfrac{T}{2}$ $\qquad (4)$

RADIATION FLUX AT A POINT BY A CYLINDRICAL SOURCE

$$\int_{-L}^{L}\int_{-R}^{R}\int_{-\sqrt{R^2-Z^2}}^{\sqrt{R^2-Z^2}} \frac{\alpha \qquad dx\, dy\, dz}{4\pi|\overrightarrow{PS}|^2 \quad \exp(a\Sigma^t + b\Sigma^s + c\Sigma^a)}$$

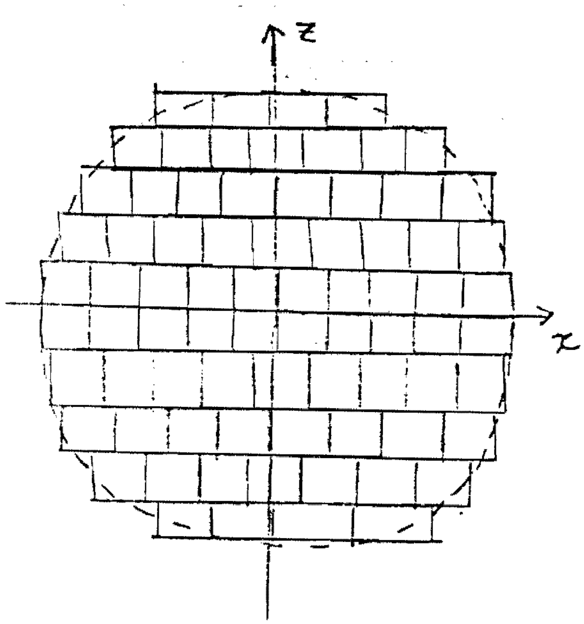
Where α = Decay rate ($cm^{-3}\ sec^{-1}$)

$\Sigma^t, \Sigma^s, \Sigma^a$ macroscopic absorption cross-section of target, source and air respectively.

This integration can be discretized into summati on of the contributions of small source volumes.

$$\sum_{i=1}^{\ell}\sum_{j=1}^{m}\sum_{k=1}^{n} \frac{\alpha \qquad \Delta xk \quad \Delta zj \quad \Delta y\ell}{4\pi\,(|\overrightarrow{PS}|_{\ell mn})^2 \cdot \exp(a_{\ell mn}\Sigma^t + b_{\ell mn}\Sigma^s + c_{\ell mn}\Sigma^a)}$$

DIVISION OF A CYLINDER



In the direction of Y, cylinder is divided into 5 or 10 sections according to the length $[\widehat{ps}]$.

5 : TAPE 8
10 : TAPE 7

Point M_1 (Cross point of $\overrightarrow{sp}$ and Top Surface)

It is the root of two equations (1) and (3)

$$z = H$$

$$X = A_x H + b_x$$

$$Y = \frac{H - b_z}{A_z}$$

Note: If $Y_p = Y_s$, $Y = Y_p = Y_s$.

Point M_2 (cross point of $\overrightarrow{sp}$ and cylinder surface)

It is the root of two equations (1) and (2)

$$x = \pm\sqrt{z^2 - R^2}$$

$$(z^2 - R^2) = A_x^2 z^2 + 2 A_x b_x z + b_x^2$$

$$z = \frac{A_x b_x + \sqrt{A_x^2 b_x^2 + (1 - A_x^2)(b_x^2 + R^2)}}{(1 - A_x^2)}$$

$$x = A_x z + b_x$$

$$y = \frac{z - b_z}{A_z}$$

$$X = A x t + b^x$$

$$Y = \frac{z - b}{A_z}$$

Note! If $Y_p = Y_s$, $Y = Y_p = Y_s$

Flight Lengths (a,b,c, in the figure)

$a = |\overrightarrow{PM_1}|$
$b = |\overrightarrow{sM_2}|$
$c = |\overrightarrow{M_1M_2}|$

Input Description

Card 1 8 Real numbers in a line
(one or more blank is needed between numbers)

x sec (i) $i = 1,3$

Macroscopic Absorption cross sections in the order of target, source and air. (cm^{-1})

L Half the length of cylinder (cm)

R Radius of cylinder (cm)

H The distance between center of cylinder and top surface of target (cm)

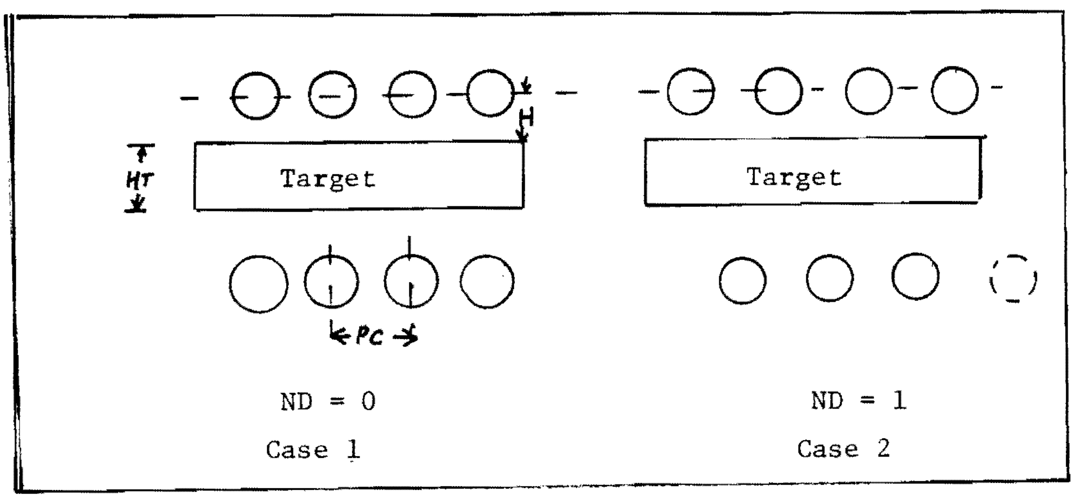
HT The thickness of target

AL Activity of source (sec^{-1} cm^{-3})

PC Pitch between two adjascent cylinders

Card 2 1 integer, 1 real, 6 integers in a line

ND The option for the location of sources



NL	Number of cylinders in the left
NR	Number of cylinders in the right
NRL	Number of cylinders in the left of the opposite side
NLL	Number of cylinders in the right of the opposite side
NPOINT	Number of target points at which the fluxes are calculated
NPLOT	The direction of points to be calculated

NPLOT - 0	no plot
NPLOT = 1	x - direction (only x-coordinates are to be changed.
NPLOT = 2	y - direction (only y-coordinates are to be changed.
NPLOT = 3	z - direction (only z-coordinates are to be changed

CARD 3 3 real numbers in each line of NPLOT lines

xpp	x - coordinate of target point
yp	y - coordinate of target point
zpp	z - coordinate of target point origin is the center of cylinder

Example 1.

	ND	PC	NL	NR	NRL	NLL	NPOINT	NPLOT
Case 1	0	PC	1	2	1	2	7	1
Case 2	1	PC	1	2	1	3	3	2

Example 2 (only one source)

ND = 1 NL = NR = NRL = NLL = 0

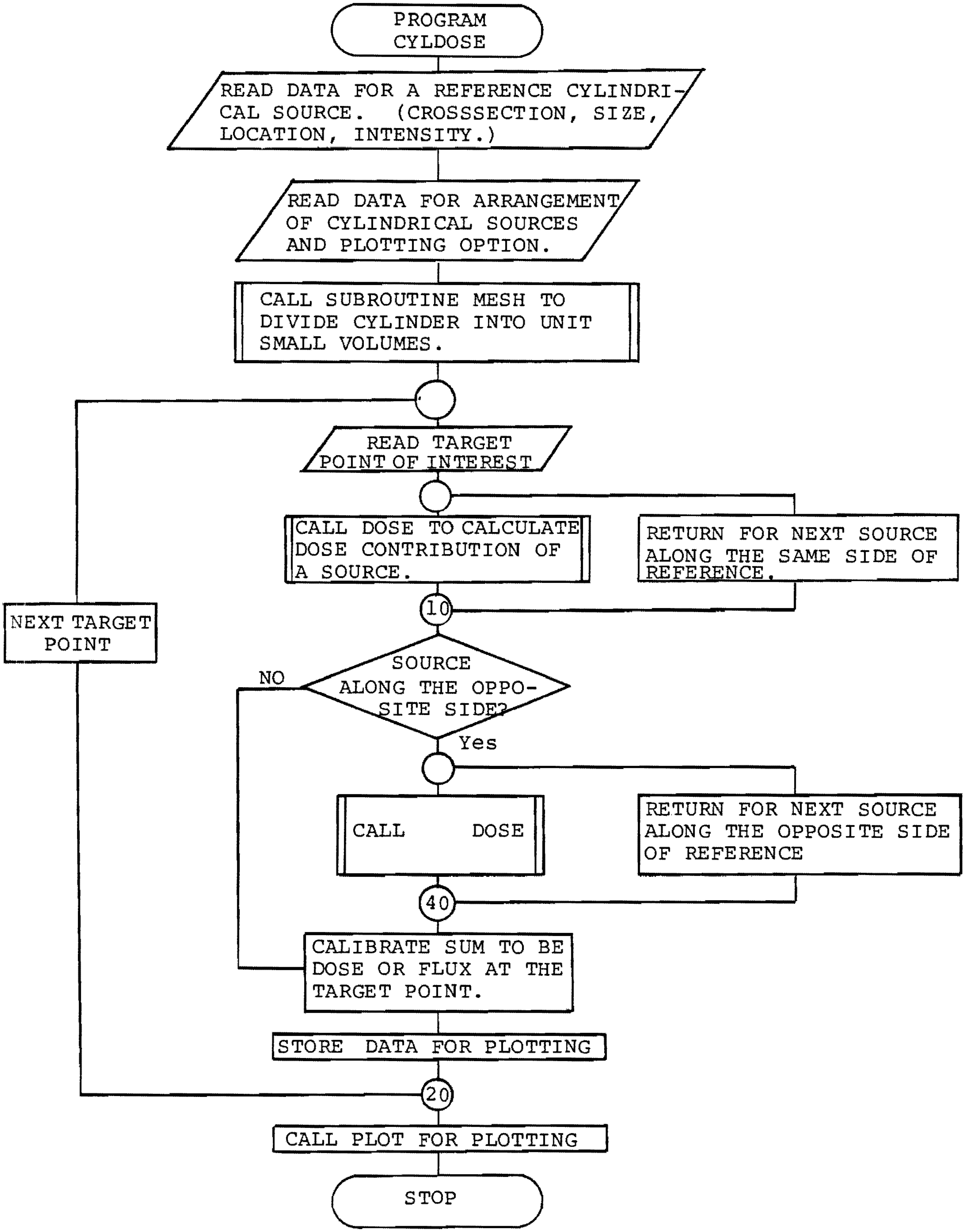
Example 3 (Symmetric Source)

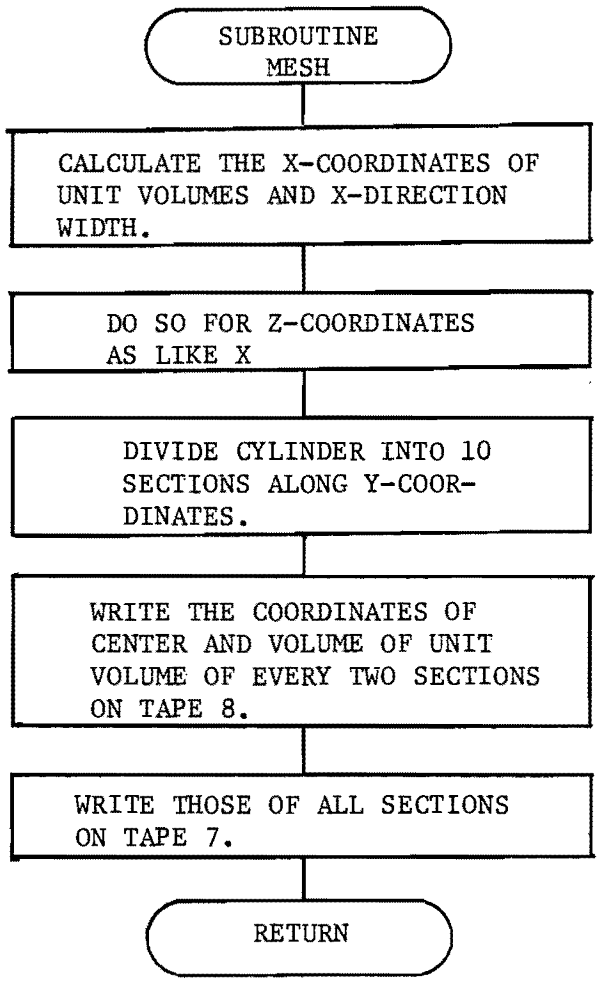
ND = 0 NL = NR = NRL = NLL = 0

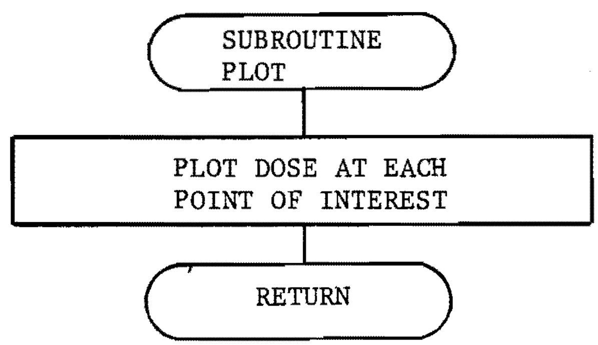
Control of the Program

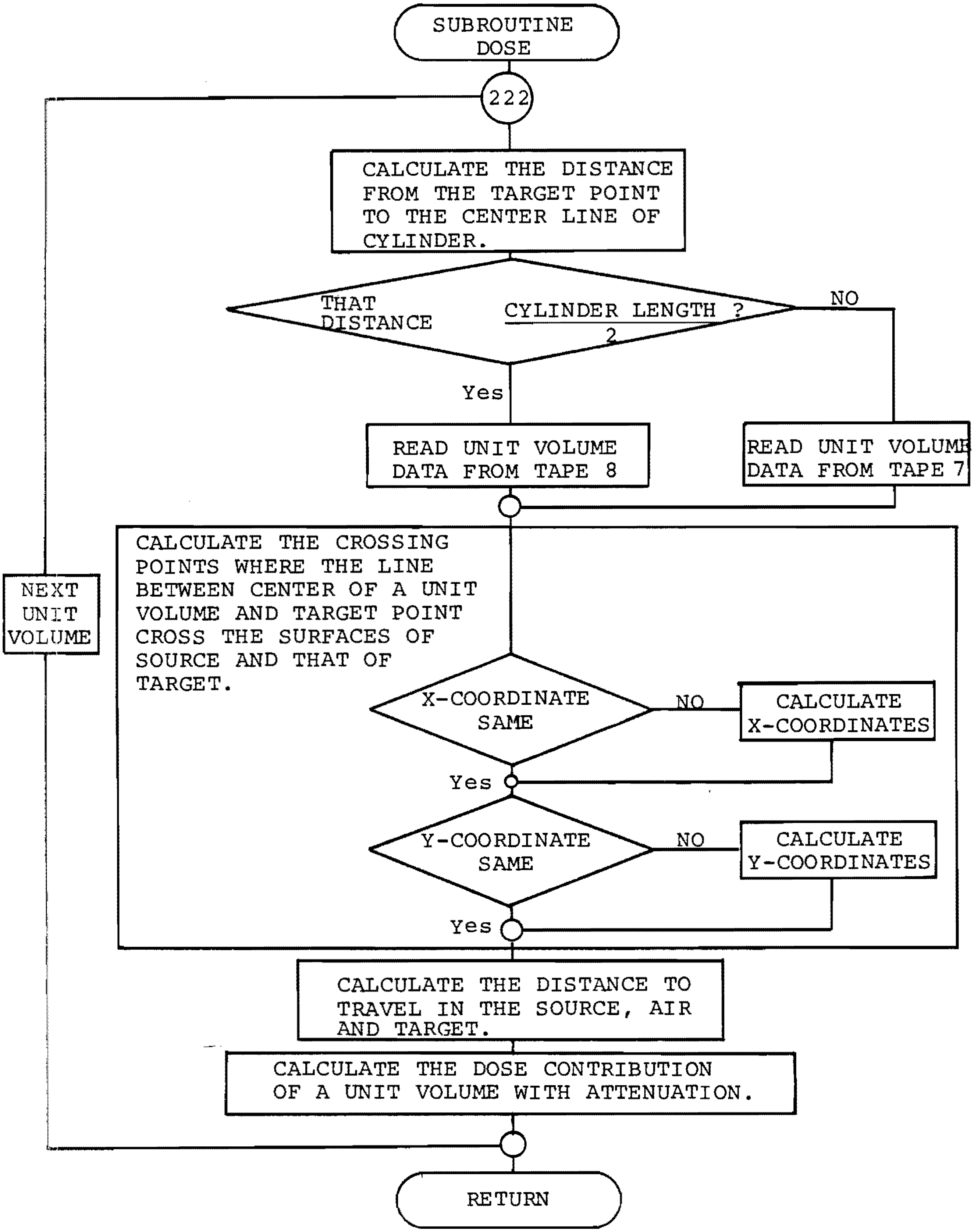
```
AT, CALCOMP / UN = LIBRARY
$ LIBRARY, CALCOMP
G,ACPLOTB, IN  ACIN    =
ACPLOT B ,, ACOUT
SAVE, TAPE 9
PLOTCV, TAPE 9
RP, ACOUT
```

ACIN and ACOUT are input and output file names. They are arbitrary which user can designate as he or she wants.


PROGRAM CYLDOSE
READ DATA FOR A REFERENCE CYLINDRICAL SOURCE. (CROSSSECTION, SIZE, LOCATION, INTENSITY.)
READ DATA FOR ARRANGEMENT OF CYLINDRICAL SOURCES AND PLOTTING OPTION.
CALL SUBROUTINE MESH TO DIVIDE CYLINDER INTO UNIT SMALL VOLUMES.
READ TARGET POINT OF INTEREST
CALL DOSE TO CALCULATE DOSE CONTRIBUTION OF A SOURCE.
RETURN FOR NEXT SOURCE ALONG THE SAME SIDE OF REFERENCE.
10
NEXT TARGET POINT
SOURCE ALONG THE OPPOSITE SIDE?
NO
Yes
CALL DOSE
RETURN FOR NEXT SOURCE ALONG THE OPPOSITE SIDE OF REFERENCE
40
CALIBRATE SUM TO BE DOSE OR FLUX AT THE TARGET POINT.
STORE DATA FOR PLOTTING
20
CALL PLOT FOR PLOTTING
STOP


SUBROUTINE MESH
CALCULATE THE X-COORDINATES OF UNIT VOLUMES AND X-DIRECTION WIDTH.
DO SO FOR Z-COORDINATES AS LIKE X
DIVIDE CYLINDER INTO 10 SECTIONS ALONG Y-COORDINATES.
WRITE THE COORDINATES OF CENTER AND VOLUME OF UNIT VOLUME OF EVERY TWO SECTIONS ON TAPE 8.
WRITE THOSE OF ALL SECTIONS ON TAPE 7.
RETURN


SUBROUTINE PLOT
PLOT DOSE AT EACH POINT OF INTEREST
RETURN


SUBROUTINE DOSE
222
CALCULATE THE DISTANCE FROM THE TARGET POINT TO THE CENTER LINE OF CYLINDER.
THAT DISTANCE
CYLINDER LENGTH ?
2
NO
Yes
READ UNIT VOLUME DATA FROM TAPE 8
READ UNIT VOLUME DATA FROM TAPE 7
NEXT UNIT VOLUME
CALCULATE THE CROSSING POINTS WHERE THE LINE BETWEEN CENTER OF A UNIT VOLUME AND TARGET POINT CROSS THE SURFACES OF SOURCE AND THAT OF TARGET.
X-COORDINATE SAME
NO
CALCULATE X-COORDINATES
Yes
Y-COORDINATE SAME
NO
CALCULATE Y-COORDINATES
Yes
CALCULATE THE DISTANCE TO TRAVEL IN THE SOURCE, AIR AND TARGET.
CALCULATE THE DOSE CONTRIBUTION OF A UNIT VOLUME WITH ATTENUATION.
RETURN

E-26-633

Georgia Institute of Technology

A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
SCHOOL OF MECHANICAL ENGINEERING

September 4, 1984

Please reply to:

NUCLEAR ENGINEERING AND
HEALTH PHYSICS PROGRAM
CHERRY EMERSON BUILDING
GEORGIA INST. OF TECH.
ATLANTA, GEORGIA 30332 U.S.A.

Dr. Russell E. Eibling
Waste Processing Technology Division
Savannah River Laboratory
E.I. Du Pont de Nemours & Co.
Aiken, SC 29808

Final Progress Report - Project E-26-633

Dear Dr. Eibling:

During the past month we have tied up some loose ends in the project and improved several of the calculations. The results are summarized in the enclosed Addendum to the Final Report. As you will see the new calculations arrive at a somewhat more favorable value for plant capacity and required source strength, thus reducing the shielding requirements considerably.

This concludes our commitments under the present contract. As I mentioned before we would be glad to do some further work in this area, in view of the rising general interest both in constructive utilization of radioactive waste materials and in the use of radiation as an alternative pasteurization and food preservation technology.

It has been a pleasure to work with you on this project.

Yours sincerely

Geoffrey G. Eichholz
Regents' Professor

GGE/sm
cc: T.F. Craft
O.H. Rodgers (OCA)

DESIGN OF A SEWAGE IRRADIATOR USING CESIUM - 137 WASTE FORMS

ADDENDUM TO THE FINAL REPORT

PROJECT E-26-633 (SRP PURCHASE ORDER AX0598189)

GEOFFREY G. EICHHOLZ

PROJECT DIRECTOR

SUBMITTED TO

WASTE DISPOSAL TECHNOLOGY DIVISION

SAVANNAH RIVER LABORATORY

E.I. Du PONT de NEMOURS & CO.

August, 1984

Introduction

At the end of June 1984 a Final Report was submitted to the Project Sponsor, Savannah River Laboratory, which summarized the work done in designing a sewage sludge irradiator based on the use of vitrified Cs - 137 waste cylinders. At that time dose calculations had been based on 40 cm long sources and as a consequence an excessively large number of sources had to be employed and the plant capacity appeared low, although mechanically it was based on the assumption that 2 - meter long sources would be employed.

Since submission of the final report, additional dose distributions have been calculated using the 2m long sources and integrated doses have been computed for target volumes passing at different positions. This Report Addendum summarizes the results of these calculations.

Dose Distributions

The source - target geometry assumed is that shown in Figures 4 and 5 of the final report. The dried sludge, density 0.5 g/ cc travels horizontally between two rows of source cylinders, containing 4 and 3 cylinders respectively, oriented at right angles to the direction of target movement. The X - direction is taken as the direction of target travel, the Y- direction along the source axes and Z in the vertical direction. Fig. 1 illustrates the main orientations and the location of several sample points. Dose distributions were calculated for the traverses shown in Fig. 1. Figs. 2 - 8 present these dose profiles. Note the dose rate coordinates, which exaggerate the steepness of the dose fall - off outside the source area. The doses calculated here represent a superposition of the contribution of all seven source elements to the central target volume. In a three-pass system with the target material passing, at the same distance, over the top three source cylinders and under the bottom four, the central pass would account for 50% of the total dose.

There are several notable features to those dose profiles, which arise from the close proximity of the target surface to the sources. One is the sharp peaking in dose rate in the target volume just below a source. The other, for the same reason, is the large difference between surface dose and center-line dose, resulting in a 2:1 dose ratio. If high dose uniformity is required, this would be undesirable. To overcome this effect the source - to - target distance would have to be increased with some loss in dosage and plant capacity.

Total Dose

Integrated doses have been recalculated for a target volume traversing the central target area at a velocity of 1 cm/min. using 2m long source cylinders. These values, which are tabulated in Table 1, correspond to the areas under dose rate curves of the type shown in Figs. 2 and 3. The doses were calculated from the centre line (Y = 0) outwards to Y = 100, symmetrical in both directions, at three depths, upper surface (Z = 15), midplane (Z - 24) and bottom surface. Doses range from a low of 0.86 M R at the far edge to nearly 4 M R in the middle. Adding the contributions of the passes over and under the two rows doubles the total dose with minimum and maximum values of 1.72 and 8 M R, respectively. If a dose of 1.0 $\pm$ 0.15 M R is the acceptable minimum dose the conveyor could be run at a speed of 2cm/min or about 4 ft/hr, Conversely, at 1cm/min the source strength could be halved to about 3 megacuries, which is considered a more acceptable and manageable source strength in terms of shielding and transportation requirements.

At a flow rate of 1cm/min, a target thickness of 20cm, a target width of 190cm, about 2.3 X 10^5 cc/hr would pass the central source region. Dried pelletized sludge has a density of 0.7g/cc; therefore, the above volume responds to 1.6 X 10^5 g/hr or about 3.9 tons/24hr. This could be doubled to about 8 tons/day with the 6MCi source.

SUMMARY

The improved dose calculations have provided a better description of the dose distribution and have indicated a possibility for reducing source strength or raising the capacity of the proposed plant.

Table 1

Calculated Integrated Doses

Coordinates as shown in Figure 1. Seven source cylinders
Integration for X =-95 to X = 50

Target Velocity 1cm/min. (Traverse time 145 min. through source region)

Position	Y	Z	Integrated dose (rads)
1	0.0 (midline)	15.0 (target top)	3.95 E06
2	0.0	24.0	1.72 E06
3	0.0	33.0	3.22 E06
4	50.0	15.0	3.75 E06
5	50.0	24.0	1.66 E06
6	50.0	33.0	3.08 E06
7	75.0	15.0	3.40 E06
8	75.0	24.0	1.49 E06
9	75.0	33.0	2.80 E06
10	100.0 (end)	15.0	2.02 E06
11	100.0	24.0	8.57 E05
12	100.0	33.0	1.65 E06

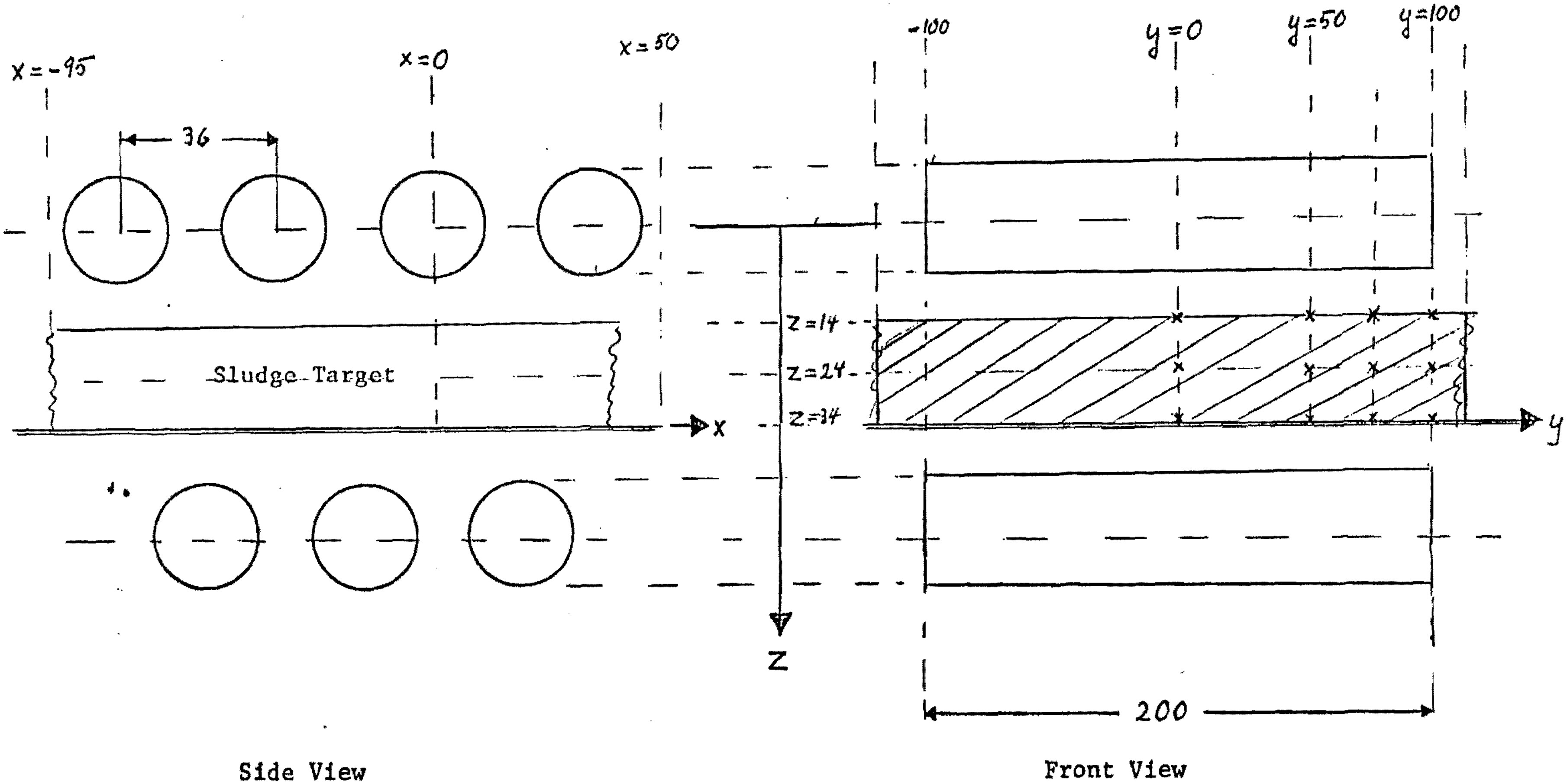
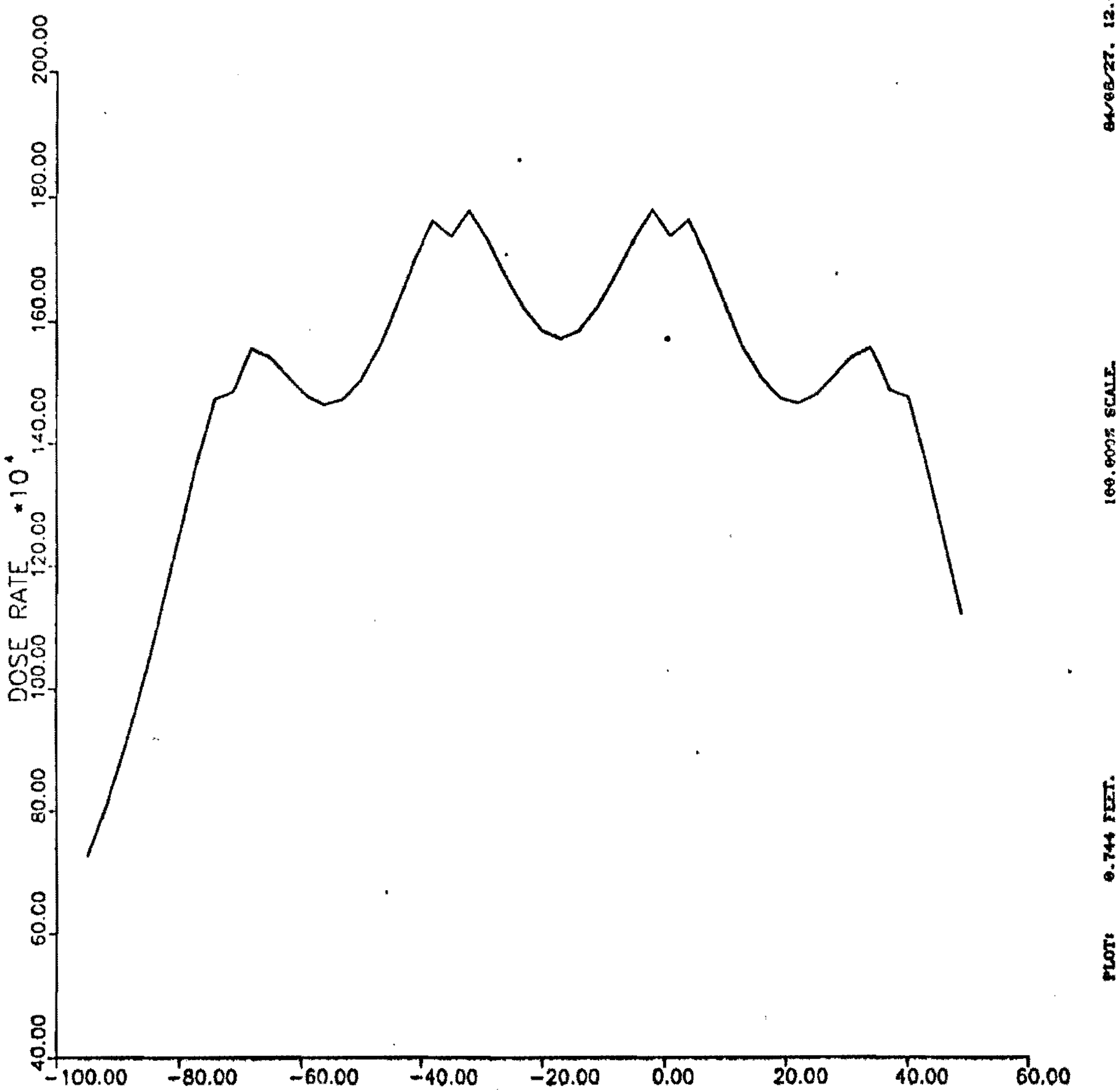


Fig. 1 Irradiation Geometry



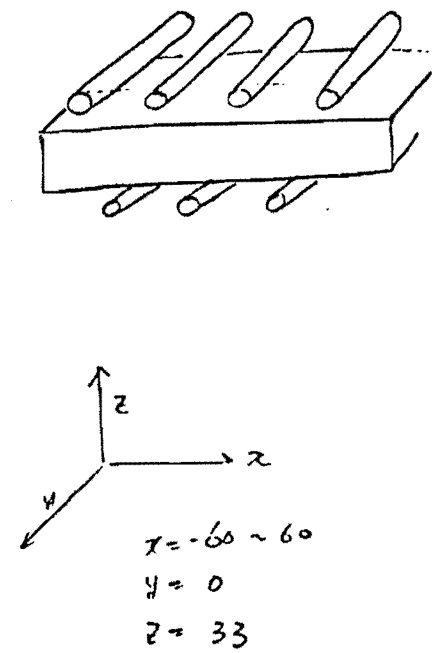
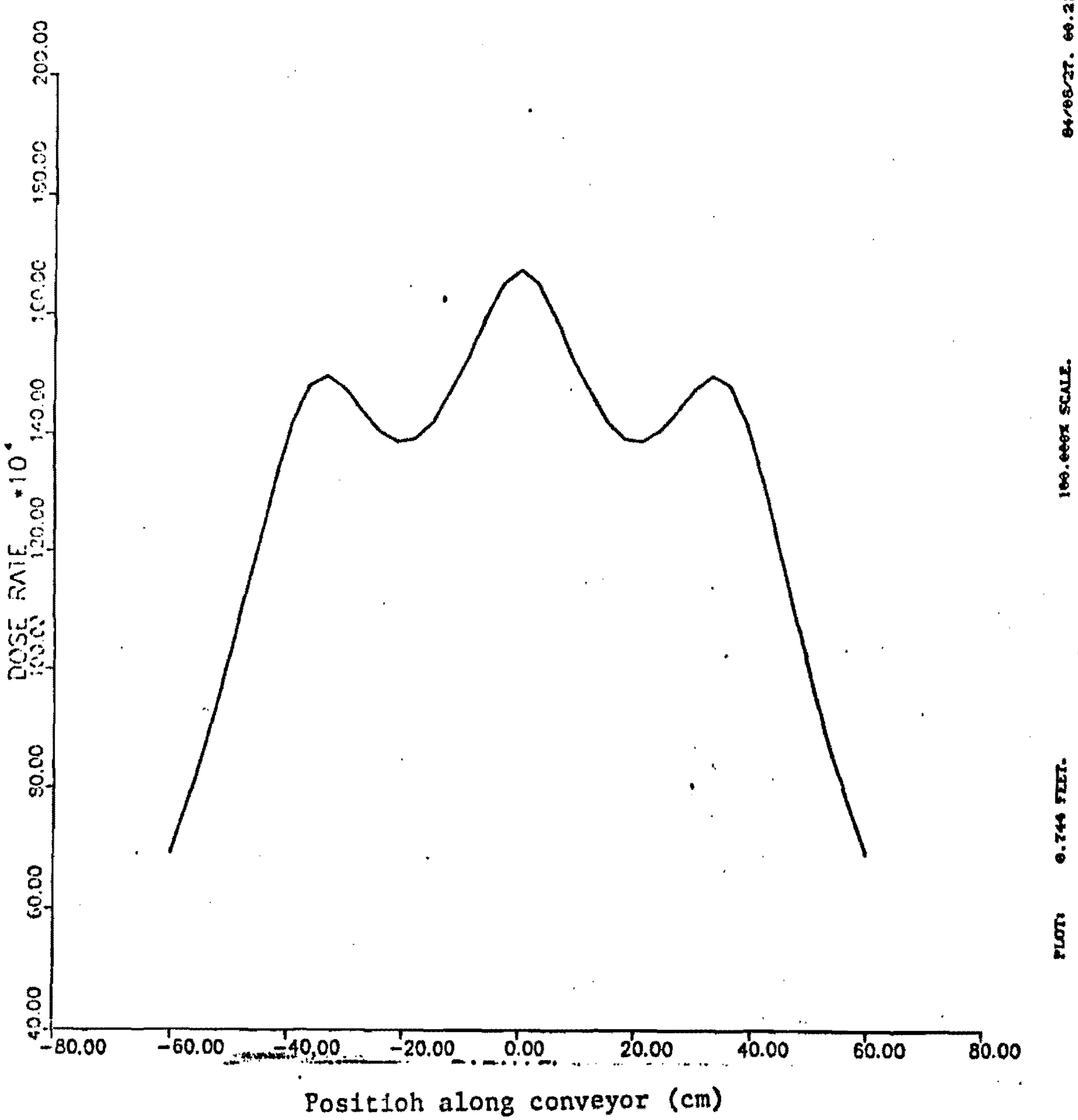


Figure 2   Dose Rate (R/hr) along upper target surface in the x-direction (conveyor motion)

$x = -60 \sim 60$
$y = 0$
$z = 15$



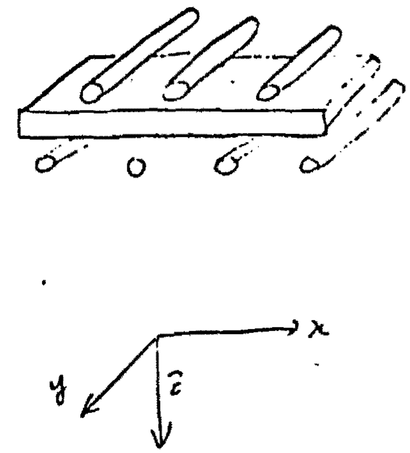
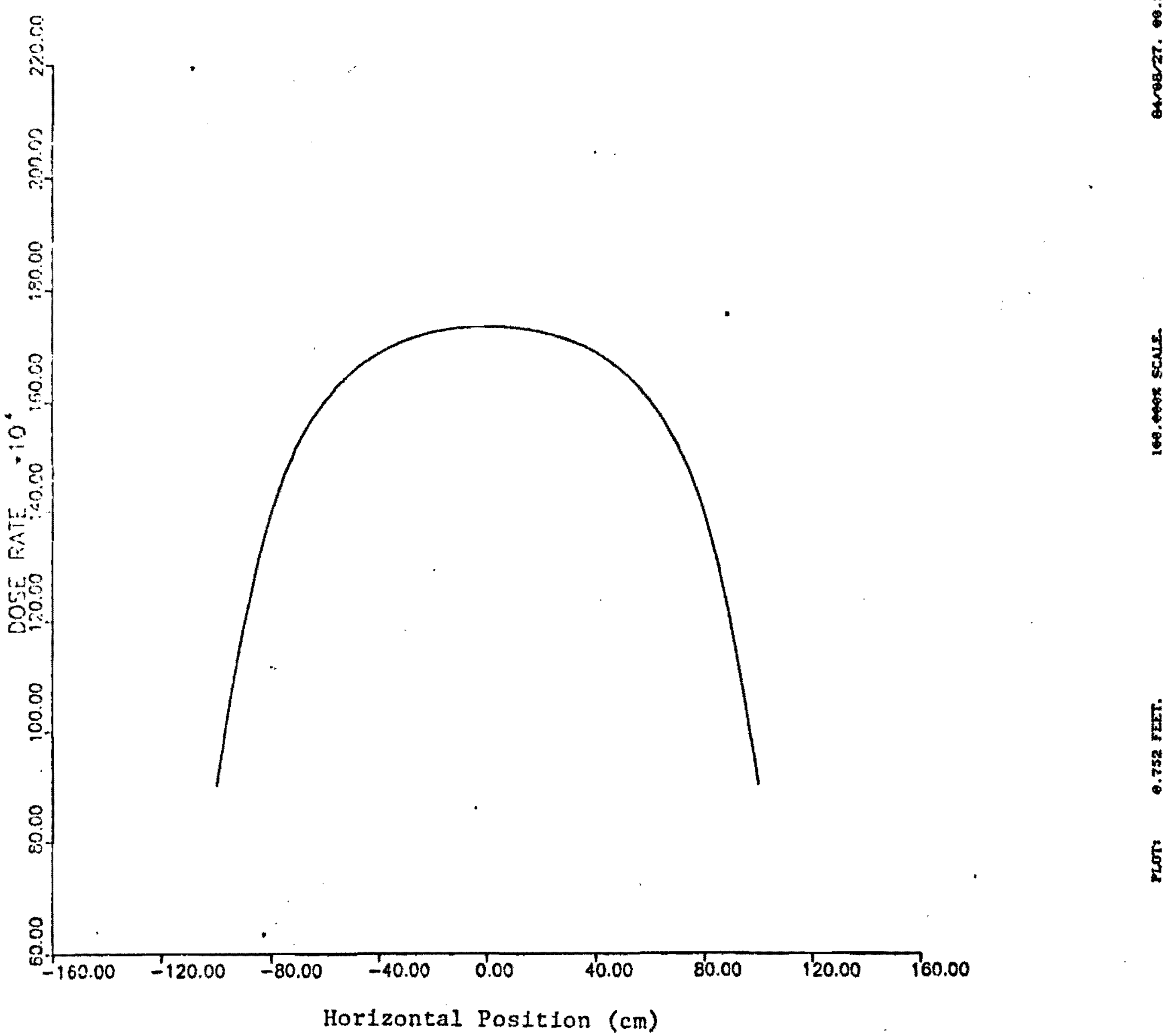


Figure 3 Dose Rate (R/hr) along lower target surface in the x-direction



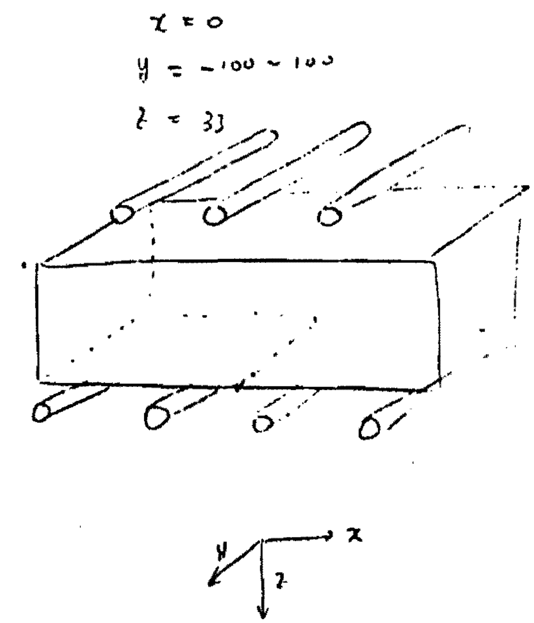
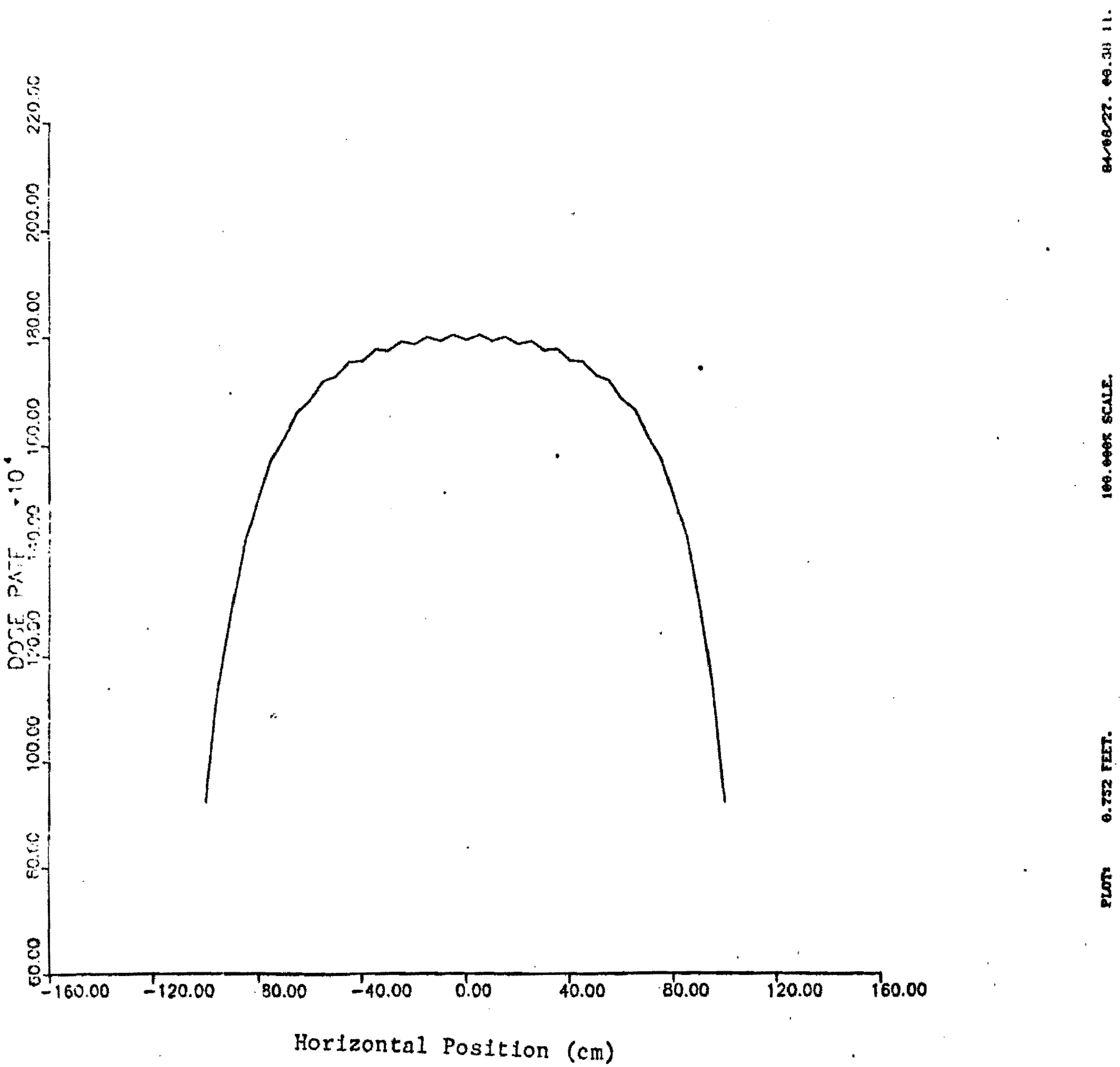


Figure 4 Dose Profile under source cylinder, center line, at upper target surface.



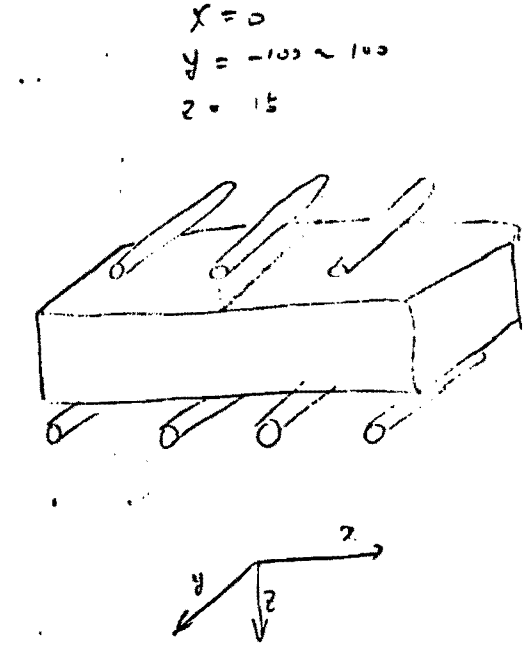


Figure 5 Dose Profile under source cylinders, center line, at lower target surface.

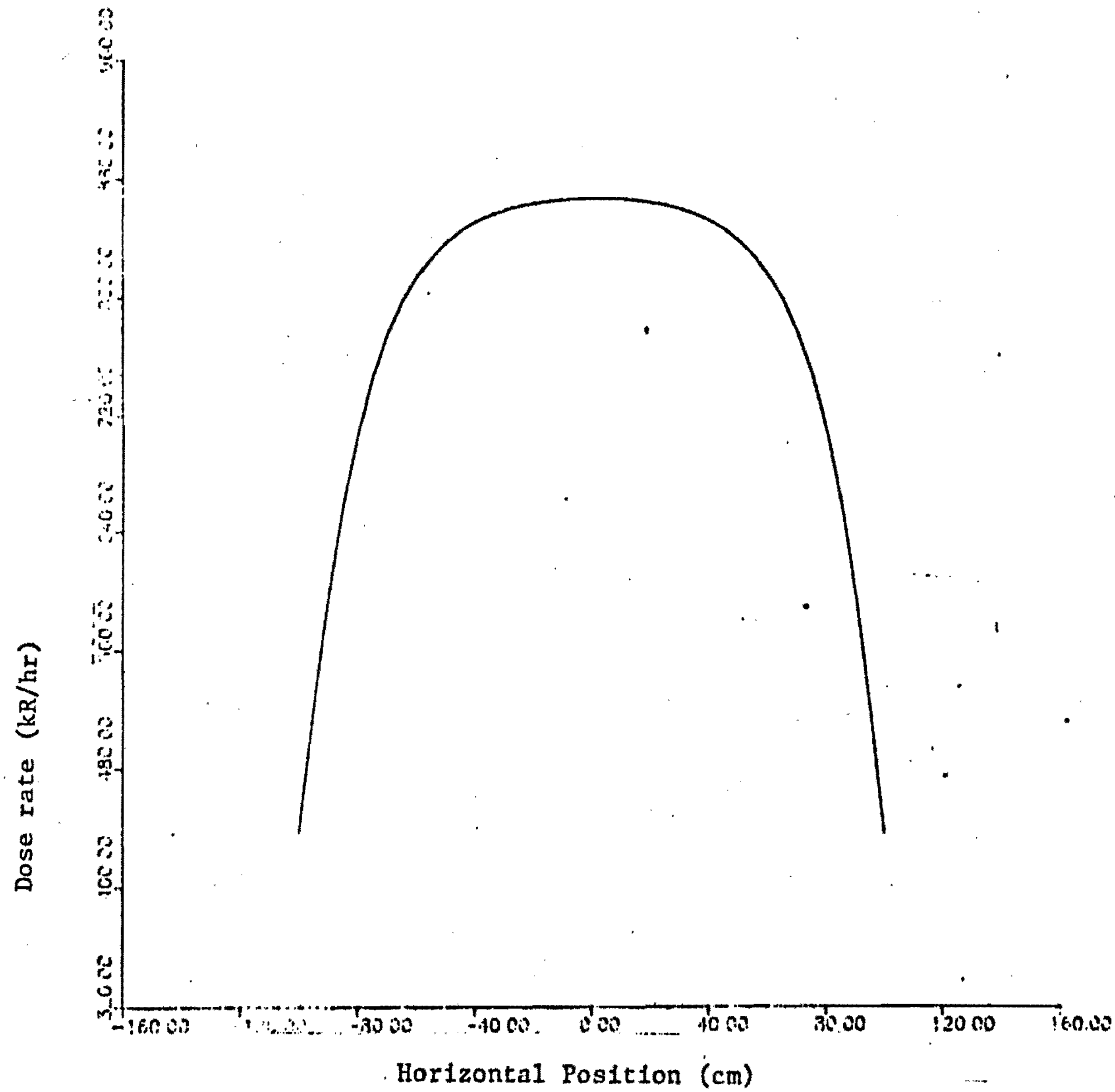
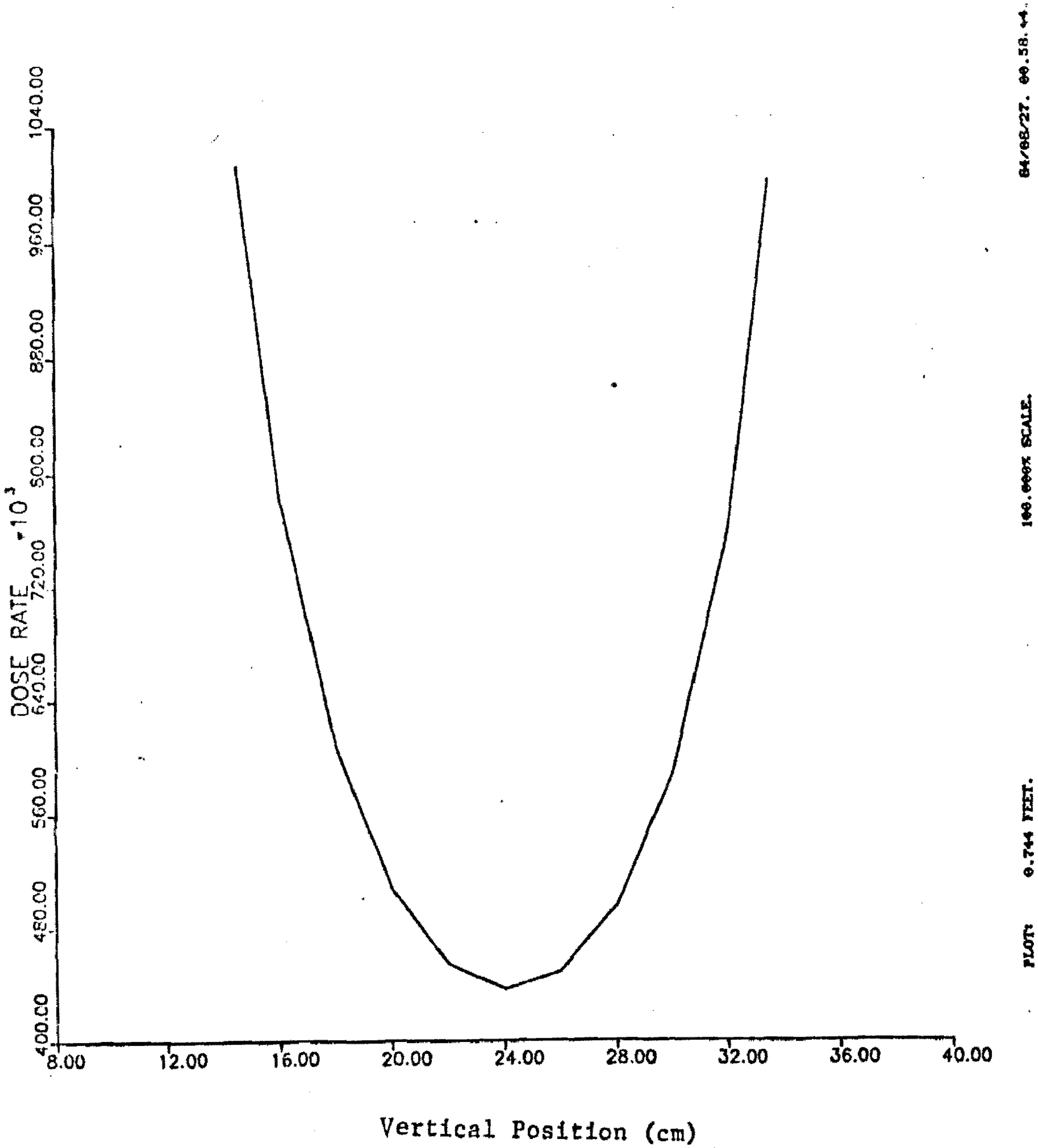


Figure 6 Dose Profile across conveyor, center of target.



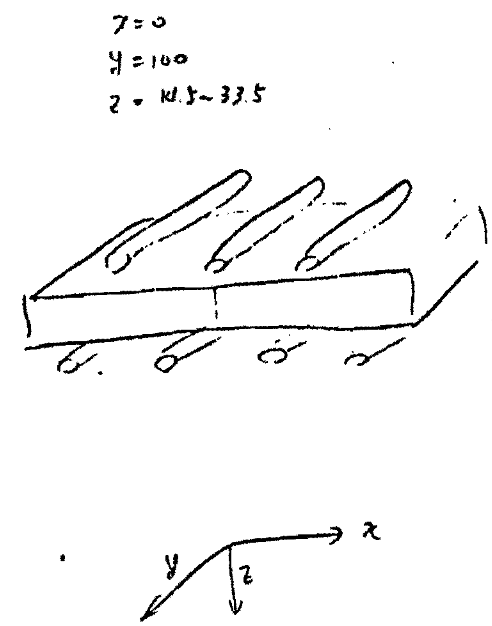
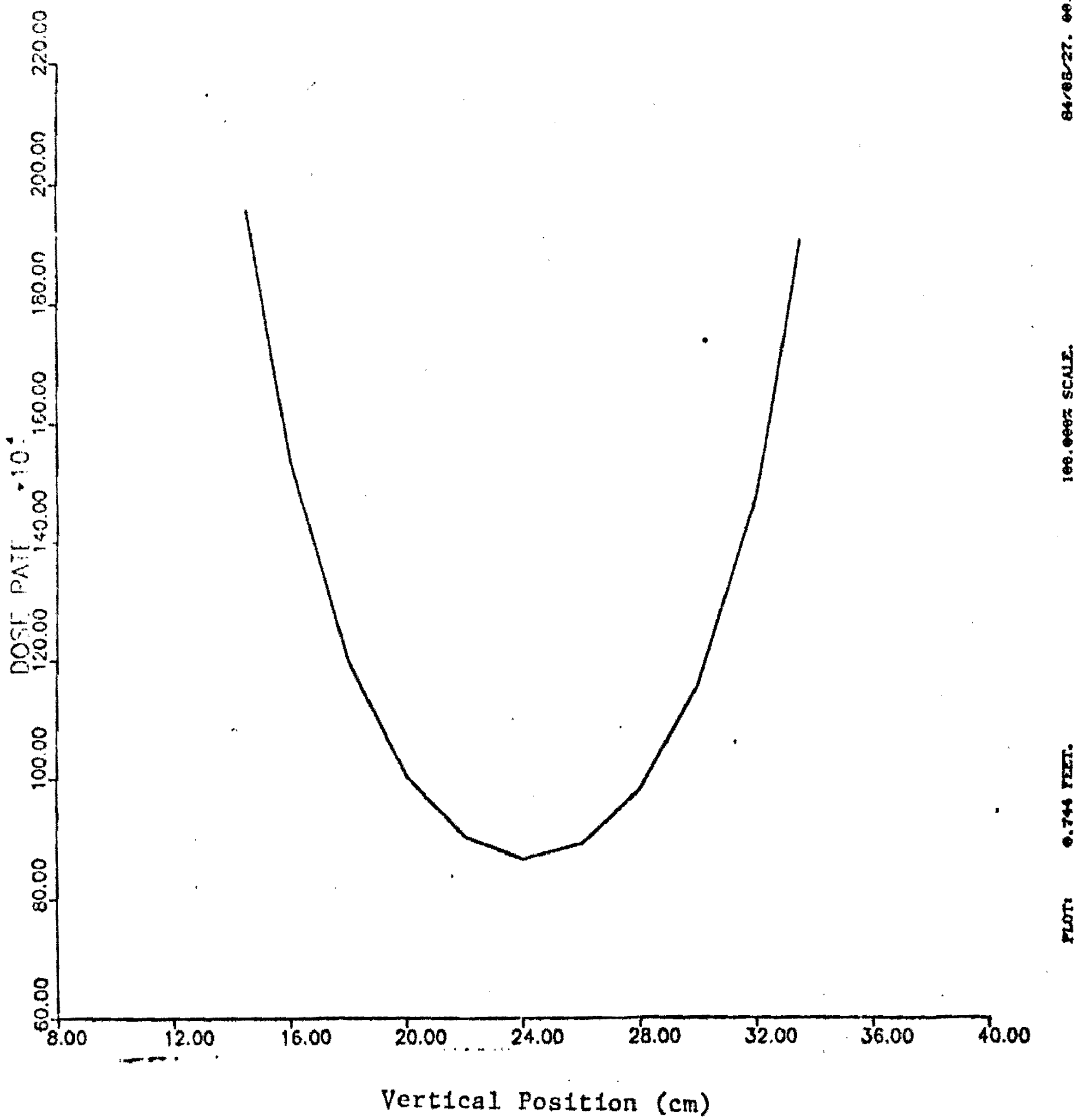


Figure 7 Vertical Dose Profile through target volume at end line of source cylinders (y=100)



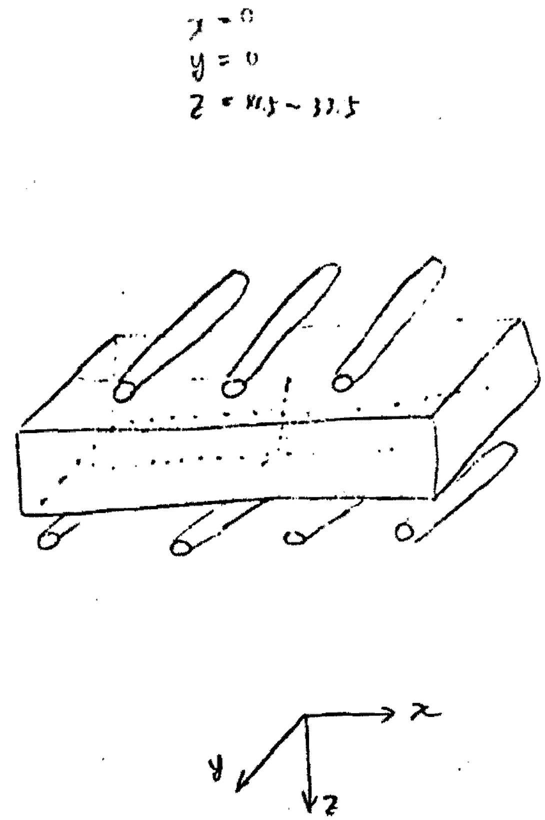


Figure 8 Vertical Dose Profile through target volume at the midpoint of the source irradiation area.